Appendix 5

8-Hour Ozone Modeling Analysis and Attainment Demonstration For South Carolina's Early Action Compact

Technical Support Document

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I. Introduction

The South Carolina 8-hour ozone modeling study was initiated in January 2000 and was designed to provide technical information relevant to attainment of an 8-hour National Ambient Air Quality Standard (NAAQS) for ozone in South Carolina, with emphasis on the Anderson/Greenville/Spartanburg, Aiken/Augusta, Columbia, Florence/Darlington, and Rock Hill areas. In addition, the study included technology transfer, training, and support for the South Carolina Department of Health and Environmental Control (SCDHEC) in setting up and conducting planned future-year emission-reduction and/or control-strategy simulations.

The United States Environmental Protection Agency (EPA) has provided an option for areas currently meeting the 1-hour ozone standard, like those in South Carolina, to attain the 8-hour ozone standard by December 31, 2007, and obtain cleaner air sooner than federally mandated. This option offers a more expeditious time line for achieving emissions reductions than expected under the EPA's 8-hour ozone implementation rulemaking, while providing "fail-safe" provisions for the area to revert to the traditional State Implementation Plan (SIP) process if specific milestones are not met. Through the development of this Early Action Compact (EAC), local, state, and EPA agree to work together to develop and implement local and state early action plans. Based on the modeling results, portions of the plans may become a part of the state early action SIP to reduce ground-level ozone concentrations to comply with the 8-hour ozone standard by December 31, 2007, and maintain the standard beyond that date. Failure to meet the obligations outlined in this EAC will result in immediate reversion to the traditional non-attainment designation process as required in the Clean Air Act (CAA).

South Carolina has chosen to take part in the Early Action Compact. The 8-hour ozone modeling study has been modified to meet the expectations of the Early Action Compact.

This report summarizes the methods and results of the photochemical modeling application for South Carolina. The modeling effort included the application of the variable-grid Urban Airshed Model (UAM-V) photochemical modeling system for one multi-day simulation period, evaluation of model performance, and use of the modeling system to estimate ozone concentrations for 2007, 2012, and 2017. The original 8-hour ozone modeling study planned to estimate ozone concentrations in 2010 as part of the attainment demonstration. The future year inventory for 2010 was completed prior to the Early Action Compact documentation and did not meet the inventory guidelines listed in the EAC guidance. To update the 2010 future year inventory to meet the EAC guidance would have been too time consuming to meet the deadlines for the EAC process. In addition, the 2010 future year emissions inventory is located between the 2007 and 2012 future year emissions inventories and thus would provide minimal additional information for the EAC process. As such, the 2010 future year emissions inventory is not included in this document. An application of current 8-hour ozone attainment demonstration procedures was also conducted. The databases and results obtained as part of this study may be used to support the early action compact process and the development of a State Implementation Plan (SIP) for South Carolina, related to the 8-hour ozone standard.

A. Background and Objectives

The South Carolina modeling analysis effort was primarily designed to provide technical information related to 8-hour ozone issues in South Carolina, specifically to begin to develop a basis for meeting regulatory modeling requirements and for longer-term decision making. Recent monitored ozone concentration data suggest that several areas within the state may be designated as nonattainment areas under an 8-hour National Ambient Air Quality Standard (NAAQS) for ozone. The standard requires that the average, over three consecutive years, of each year's fourth highest ozone concentration be less than 85 parts per billion (ppb) for a given monitoring site. Initial compliance with this standard was expected to be based on data for the period 1997-1999; the modeling episode was also selected from these years. Due to delays in implementing the 8-hour ozone standard, compliance is now expected to be determined using data collected during the period 2001-2003.

To provide perspective on the 8-hour ozone issues in the region, Tables 1-1a through 1-1e list the 8-hour ozone design values (the averages calculated for the NAAQS as described above) for the areas of interest for the most recent, running three-year periods for which data are available: 1997-1999, 1998-2000, 1999-2001, 2000-2002, and 2001-2003. For most areas, the calculated design values are similar for all three periods. A designation of nonattainment relative to the 8-hour ozone standard requires that air quality modeling techniques be applied as part of an attainment demonstration.

Table 1-1a.
1997-1999 8-hour ozone "design" values for the South Carolina areas of interest.

Area	1997-1999 Design Value (ppb)
Aiken/Augusta	89
Anderson/Greenville/Spartanburg	95
Columbia	91
Darlington/Florence	88
Rock Hill	86

Table 1-1b.
1998-2000 8-hour ozone "design values" for the South Carolina areas of interest.

Area	1998-2000 Design Value (ppb)
Aiken/Augusta	92
Anderson/Greenville/Spartanburg	95
Columbia	95
Darlington/Florence	89
Rock Hill	84

Table 1-1c.
1999-2001 8-hour ozone "design values" for the South Carolina areas of interest.

Area	1999-2001 Design Value (ppb)
Aiken/Augusta	87
Anderson/Greenville/Spartanburg	92
Columbia	94
Darlington/Florence	87
Rock Hill	83

Table 1-1d.
2000-2002 8-hour ozone "design values" for the South Carolina areas of interest.

Area	2000-2002 Design Value (ppb)
Aiken/Augusta	88
Anderson/Greenville/Spartanburg	92
Columbia	93
Darlington/Florence	86
Rock Hill	84

Table 1-1e.
2001-2003 8-hour ozone "design values" for the South Carolina areas of interest.

Area	2001-2003 Design Value (ppb)
Aiken/Augusta	81
Anderson/Greenville/Spartanburg	87
Columbia	89
Darlington/Florence	82
Rock Hill	84

As noted in the above tables, only the Anderson/Greenville/Spartanburg area and the Columbia area have been designated nonattainment for the 8-hour ozone standard.

A modeling platform was established through the development of the modeling databases, model performance evaluation, and use of the modeling system to examine the effects of future-year emissions changes on ozone concentrations for the modeling episode period.

The South Carolina modeling analysis was designed in accordance with draft EPA guidance (EPA, 1999a) for using modeling and other analyses for 8-hour ozone attainment demonstration purposes. The modeling analysis components include a comprehensive episode selection analysis to identifying suitable periods for modeling, application and evaluation of a photochemical modeling system for one multi-day simulation period, projection of emissions and ozone concentrations for this simulation period in 2007, 2012, and 2017, and evaluation of the effects of various emissions reduction scenarios on future-year ozone air quality. While photochemical modeling is currently the best available and most widely used technique for estimating the effects of emission changes on future-year ozone levels and for evaluating attainment strategies, EPA also recommends that additional analysis of observed data be included as part of an attainment demonstration. Thus it is anticipated that future efforts will also include the analysis of observed data to corroborate the results and conclusions of the modeling analysis.

B. Overview of the SC DHEC Modeling System

The primary modeling tools selected for use in this study include: the variable-grid Urban Airshed Model (UAM-V) Version 1.31, a regional- and urban-scale, nested-grid photochemical model; the Emission Preprocessor System (EPS2.5), for preparation of model ready emission inventories; the Biogenic Emission Inventory System with 4km resolution land-crop data (BEIS-2+), for estimating biogenic emissions; the MOBILE6 model, for estimating motor-vehicle emissions; and the Pennsylvania State University/National Center for Atmospheric Research (PSU/NCAR) Mesoscale Model, Version 5 (MM5), for preparation of the meteorological inputs. The UAM-V modeling system outputs were summarized and displayed using the UAM-V Postprocessing System (UPS) and the SC DHEC ACCESS Database for Visualizing and Investigating Strategies for Ozone Reduction (ADVISOR). Figure 1-1 provides an overview of the SC DHEC modeling system, including key input data requirements, UAM-V input files, and interactions among the modeling system components.

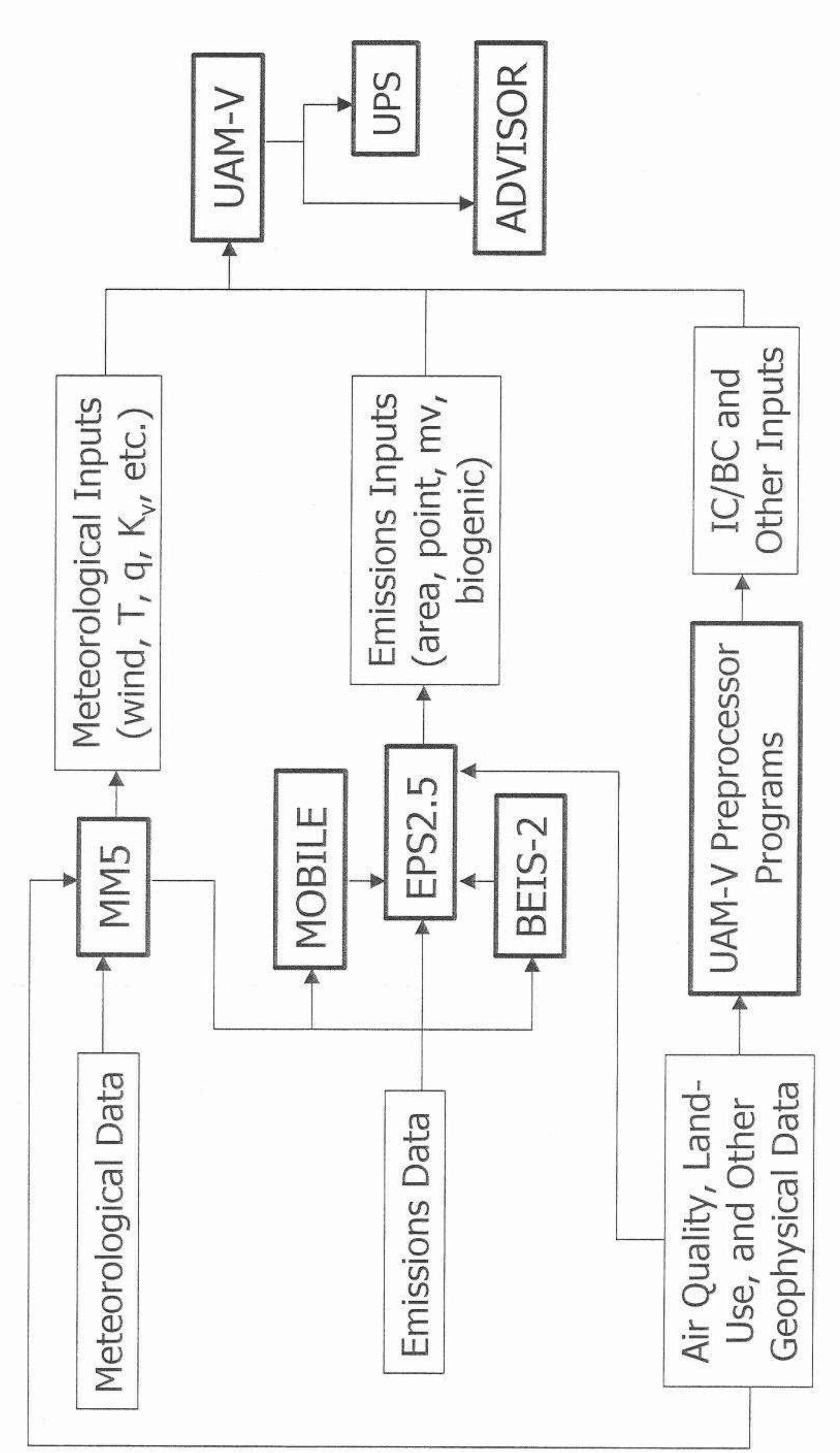


FIGURE 1-1
Schematic diagram of the photochemical modeling system used for the South Carolina 8-hour ozone modeling analysis.

C. Overview of the UAM-V Modeling System

The variable-grid Urban Airshed Model (UAM-V) is a three-dimensional photochemical grid model that calculates concentrations of pollutants by simulating the physical and chemical processes in the atmosphere. The basis for the UAM-V is the atmospheric diffusion or species continuity equation. This equation represents a mass balance that includes all of the relevant emissions, transport, diffusion, chemical reactions, and removal processes in mathematical terms.

The major factors that affect photochemical air quality include:

- The pattern of emissions of NO_x and volatile organic compounds (VOC), both natural and anthropogenic
- Composition of the emitted VOC and NO_x
- Spatial and temporal variations in the wind fields
- Dynamics of the boundary layer, including stability and the level of mixing
- Chemical reactions involving VOC, NO_x, and other important species
- Diurnal variations of solar insolation and temperature
- Loss of ozone and ozone precursors by dry and wet deposition
- Ambient background of VOC, NO_x, and other species in, immediately upwind of, and above the study region.

The UAM-V simulates all of these processes. The species continuity equation is solved using the following fractional steps: emissions are injected; horizontal advection/diffusion are solved; vertical advection/diffusion and deposition are solved; and chemical transformations are performed for reactive pollutants. The UAM-V performs these four calculations during each time step. The maximum time step is a function of the grid size, maximum wind velocity, and diffusion coefficient. The typical time step is 10–15 minutes for coarse (10–20 km) grids and a few minutes for fine (1–2 km) grids.

Because it accounts for spatial and temporal variations as well as differences in the reactivity of emissions, the UAM-V is ideal for evaluating the air-quality effects of emission control scenarios. This is achieved by first replicating a historical ozone episode to establish a base-case simulation. Model inputs are prepared from observed meteorological, emissions, and air quality data for the episode days using prognostic meteorological modeling and/or diagnostic and interpolative modeling techniques. The model is then applied with these inputs, and the results are evaluated to determine model performance. Once the model results have been evaluated and determined to perform within prescribed levels, the same base-case meteorological inputs are combined with *modified* or *projected* emission inventories to simulate possible alternative/future emission scenarios.

The UAM-V modeling system (Version 1.3) incorporates the Carbon-Bond IV chemical mechanism with enhanced isoprene chemistry. It represents an extension of the UAM (also referred to as UAM-IV).

The Carbon Bond Toxics Mechanism (CBM-Tox) as used in the UAM-V, is an expanded version of the Carbon Bond mechanism version IV (CBM-IV, Gery et al., 1989). The details of the development of CBM-Tox and its implementation into the UAM are described by Ligocki and Whitten (1991) and Ligocki et al. (1992). Explicit chemistry has been added for several toxic species such as benzene, 1, 3-butadiene, and naphthalene. In addition to naphthalene other polycyclic organic matter (POM) is specially treated by two surrogates based on molecular weight: POM1 for MW 160 to 220 and POM2 for heavier species. The POM surrogates include such species as the benzo-pyrenes found in diesel exhaust.

Treatment of the POM species includes a gas-particle phase distribution, which is calculated for each time step and grid cell, based upon the temperature and local total suspended particulate concentration.

The main expansion to the original chemistry of the CBM-IV involves explicit treatment of acetaldehyde (instead of ALD2, which is based on acetaldehyde chemistry as a surrogate for internal olefins and all adehydes other than formaldehyde). CBM-Tox expands ALD2 to three species (ALDX for aldehydes with more carbons than acetaldehyde, IOLE for internal olefins, and PPN for C3 and greater PAN-like compounds). Toxic formaldehyde is explicitly treated in both the original CBM-IV and CBM-Tox. However, as implemented in UAM-V primary and secondary species are provided for both acetaldehyde and formaldehyde.

When originally expanded the “Tox” version produced essentially the same results as the regular CBM-IV mechanism. However, it was subsequently realized that the higher aldehydes (ALDX) apparently photolyze to free radicals as much as four times faster than acetaldehyde. Tests have shown the CBM-Tox to give as much as 30 percent more ozone at very low VOC-to-NOx ratios compared to the standard CBM-IV; at higher ratios the two versions give essentially identical results. Coincidentally, two independent studies have been published (Simonaitis, Meagher, and Bailey, 1997, and Hess et al., 1992) which claim that the CB-IV mechanism appears to exhibit inadequate ozone performance at the lowest VOC to NOx ratios when tested against smog chamber data using comprehensive urban-like mixtures of VOC.

The UAM-Tox has been used in several projects such as the following: Guthrie et al. (1997), Ligocki et al. (1992), and Ligocki and Whitten (1992).

Features of the UAM-V modeling system include:

1. *Variable vertical grid structure:* The structure of vertical layers can be arbitrarily defined. This allows for higher resolution near the surface and facilitates matching with output from prognostic meteorological models.

2. *Three-dimensional meteorological inputs:* The meteorological inputs for UAM-V vary spatially and temporally. These are usually calculated using a prognostic meteorological model.

3. *Variable grid resolution for chemical kinetic calculations:* A chemical aggregation scheme can be employed, allowing chemistry calculations to be performed on a variable grid while advection/diffusion and emissions injections are performed on a fixed grid.

4. *Two-way nested grid:* Finer grids can be imbedded in coarser grids for more detailed representation of advection/diffusion, chemistry, and emissions. Several levels of nesting can be accommodated.

5. *Updated chemical mechanism:* The original Carbon Bond IV chemical mechanism has been updated to include the XO_2–RO_2 reaction and new temperature effects for PAN reactions. The updated chemical mechanism also supports the enhanced treatment of isoprene, hydrocarbon, and toxics species.

6. *Dry deposition algorithm:* The dry deposition algorithm is similar to that used by the Regional Acid Deposition Model (RADM).

7. *True mass balance:* Concentrations are advected and diffused in the model using units of mass per unit volume rather than parts per million. This maintains true mass balance in the advection and diffusion calculations.

8. *Plume-in-grid treatment:* Emissions from point sources can be treated by a subgrid-scale Lagrangian photochemical plume model. Pollutant mass is released from the subgrid-scale model to the grid model when the plume size is commensurate with grid cell size.

9. *Plume rise algorithm:* The plume rise algorithm is based on the plume rise treatment for a Gaussian dispersion model.

D. Modeling Grid Specification

The modeling domain for application of the UAM-V was designed to accommodate both regional and subregional influences as well as to provide a detailed representation of the emissions, meteorological fields, and ozone (and precursor) concentration patterns over the area of interest. The UAM-V modeling domain is presented in Figure 1-2 and includes a 36-km resolution outer grid encompassing the southeastern U.S; a 12-km resolution intermediate grid; and a 4-km resolution inner grid encompassing South Carolina and portions of Georgia, Tennessee, and North Carolina.

The regional extent of the modeling domain is intended to provide realistic boundary conditions for the primary area of interest and thus avoid some of the uncertainty introduced in the modeling results through the incomplete and sometimes arbitrary specification of boundary conditions. The offshore extent of the domain is designed to accommodate the simulation of over-water pollutant transport and recirculation. The use of 4-km grid resolution over the entire State of South Carolina is consistent with an urban-scale analysis of all of the areas of interest.

The UAM-V domain is further defined by eleven vertical layers with layer interfaces at 50, 100, 200, 350, 500, 750, 1000, 1250, 1750, 2500, and 3500 meters (m) above ground level (agl).

The modeling domain for application of MM5 is shown in Figure 1-3. This domain is much larger than that for UAM-V, in order to enable the simulation of any important synoptic scale features and their influence on the regional meteorology. The modeling domain consists of an extended outer grid with approximately 108-km horizontal resolution and four inner (nested) grids with approximately 36, 12, and 4-km resolution. The horizontal resolution is specified to match that for UAM-V. A one-way nesting procedure and 22 vertical levels are employed. The vertical grid is defined using the MM5 sigma-based vertical coordinate system. The layer thickness increases with height such that high resolution is achieved within the planetary boundary layer. The vertical layer heights for application of MM5 are listed in Table 1-2.

Table 1-2.
MM5 vertical levels for the SC DHEC application

Level	Sigma	Height[1] (m)
1	0.996	30
2	0.988	80
3	0.982	125
4	0.972	215
5	0.960	305
6	0.944	430
7	0.928	560
8	0.910	700
9	0.890	865
10	0.860	1115
11	0.830	1370
12	0.790	1720
13	0.745	2130
14	0.690	2660
15	0.620	3375
16	0.540	4260
17	0.460	5240
18	0.380	6225
19	0.300	7585
20	0.220	9035
21	0.140	10790
22	0.050	13355

[1] Representative heights—actual heights vary by hour and by grid.

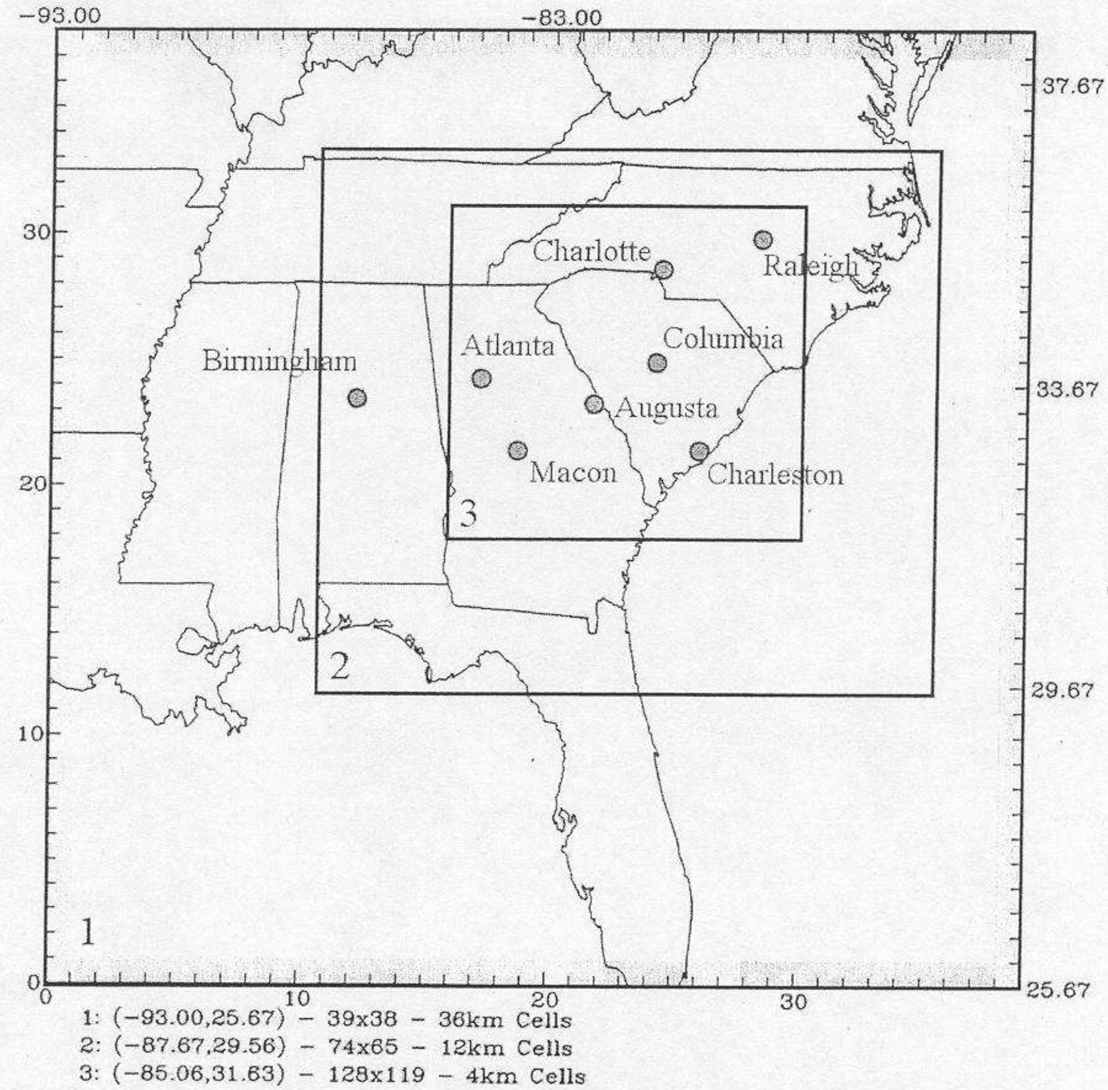


FIGURE 1-2
UAM-V modeling domain for the South Carolina 8-hour ozone modeling study.

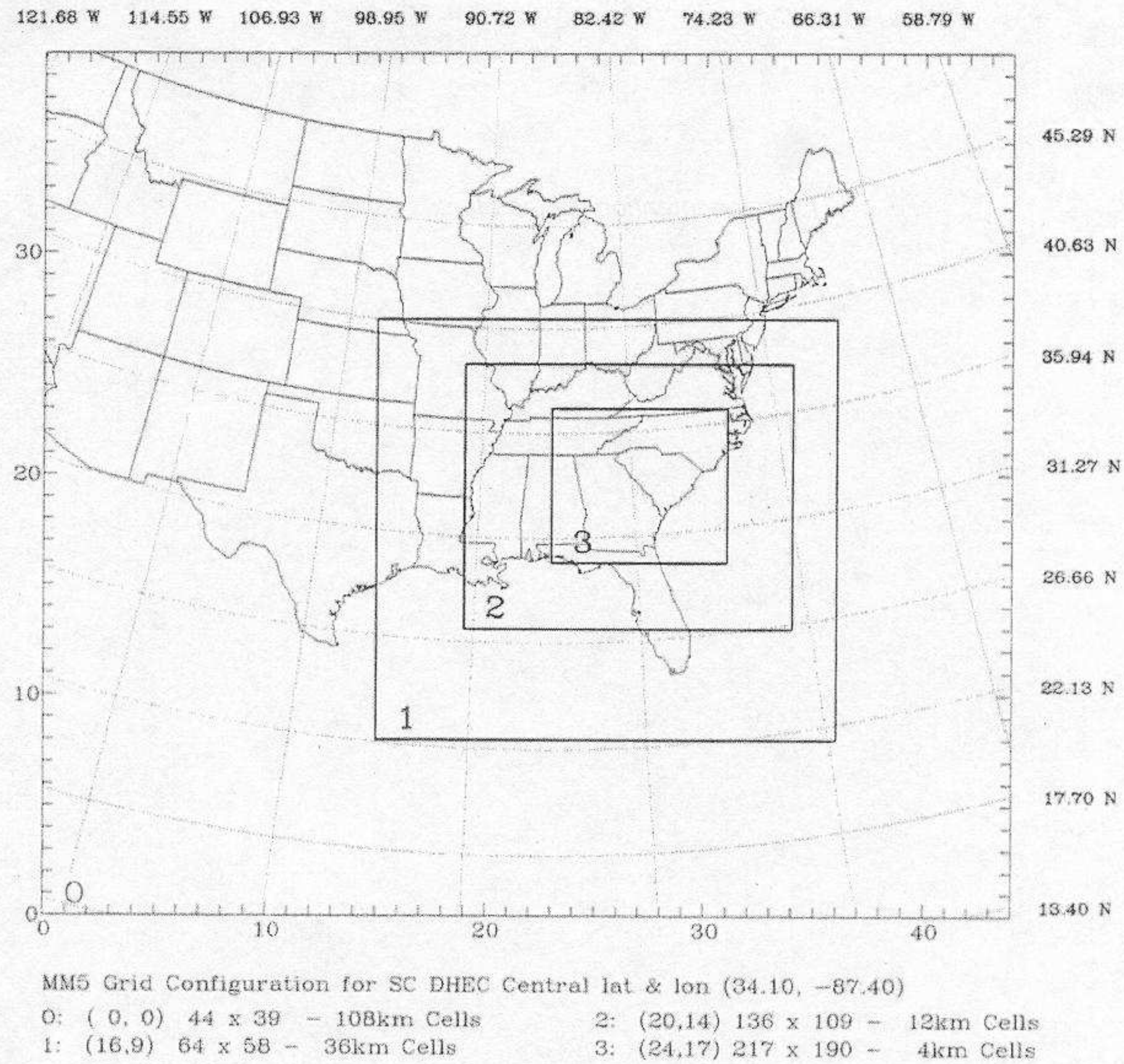


FIGURE 1-3
MM5 modeling domain for the South Carolina application.

E. Episode Selection/Simulation Periods

This section describes the methods and results of the episode selection analysis conducted to support the modeling exercise. SC DHEC performed the analysis, and major portions of this section were adapted from an SC DHEC internal report. One episode was selected for this first high-resolution photochemical model application for South Carolina.

Episode selection for the South Carolina modeling/analysis was based on a review of air quality data, and followed the methods described in the current (draft) EPA guidance (EPA, 1999a). The years 1993, 1996, 1997, and 1998 were examined. For each year considered, design values were calculated using data for the current year, previous year, and following year. Quality-assured ozone data for 1992 through 1999 were used. Additional information on the episode selection along with other episodes considered is located in appendix 18 of the early action compact SIP.

The primary objective of the episode selection analysis was to identify suitable periods for analysis and modeling related to the 8-hour ozone NAAQS for the Anderson/Greenville/Spartanburg, Aiken/Columbia, Florence/Darlington, and Rock Hill areas in South Carolina. The approach to episode selection is consistent with current (draft) EPA guidance (EPA, 1999a) on episode selection for 8-hour ozone attainment demonstration modeling. In this guidance, EPA lists the following as the most important criteria for choosing episodes:

- Monitored ozone concentrations comparable to the severity as implied by the form of the NAAQS
- Representation of a variety of meteorological conditions observed to correspond to monitored ozone concentrations of the severity implied by the form of the NAAQS
- Data availability
- Selection of a sufficient number of days so that the modeled attainment test is based on several days

EPA also provides several secondary criteria for episode selection:

- Episodes used in previous modeling exercises
- Episodes drawn from the period on which the current design value is based
- Observed concentrations are “close” to the design value for as many sites as possible
- Episodes are appropriate for as many of the nonattainment areas as possible (when several areas are being modeled simultaneously)
- Episodes that include weekend days

Methodology and Results

In accordance with EPA guidance, the primary objectives of the episode selection analysis were to identify candidate modeling episodes that

1. Represent the type of meteorological conditions that accompany ozone exceedances,
2. Are influenced by different airflow patterns (as primarily characterized by local wind speed and direction) on different days,

3. Have ozone concentrations that are representative of the design value (the guidance quantifies the latter with a range of 10 ppb),
4. Have multiple days with maximum 8-hour ozone concentrations within 10 ppb of the design value for each site/area, and
5. Accommodate as many areas of the state as possible[2].

Eight hour ozone data were examined for the years 1992 through 1999. The data were categorized according to ozone levels set forth in the guidance. Eight-hour ozone values of 64 ppb or less were categorized as "low," those from 65 ppb to 84 ppb, as "moderate," 85 ppb to 105 ppb as "high," and greater than 105 ppb as "very high." The categorized data were then examined to determine the years for which the greatest number of high ozone values occurred. These totals along with information on ozone distributions relative to design values were the basis for the selection of years for which to further examine ozone data.

The frequency of occurrence of days within each of the ozone categories is presented in Table 1-3 (The lowest category has been dropped from the table.)

Table 1-3.
Summary of maximum 8-hour ozone concentrations for South Carolina for 1992-1999

Year	Moderate	High	Very High
	65 ppb ≤ O3 < 85 ppb	85 ppb ≤ O3 < 105 ppb	≥105 ppb
1992	113	6	0
1993	827	64	7
1994	387	43	0
1995	568	45	2
1996	139	3	0
1997	861	65	0
1998	1089	190	8
1999	1072	149	5

The totals for the High and Very High categories represent the number of exceedances of the 8-hour standard for all of South Carolina for each year. There is a peak in the number of exceedances in 1993 and then again toward the end of the period. If the newly proposed 8-hour standard were in effect in 1993, South Carolina would have recorded 71 exceedances. Seven of those would have fallen in the "Very High" category. Lower ozone levels were recorded in 1992, 1994, 1995, and 1996. Based on the proposed 8 hour standard, only three exceedances would have occurred statewide during 1996. The greatest number of exceedances, 198, occurred in 1998.

2 This is an important consideration for this study, since this is the first detailed photochemical modeling exercise for South Carolina. This modeling exercise will therefore facilitate the evaluation of the emissions inventory and the ability of the modeling system to simulate ozone concentration levels and patterns both regionally and in different parts of the State.

To represent years in which a low number and high number of exceedances occurred, the years of 1993, 1996, 1997, and 1998 were analyzed. Although episode selection was carried out for all four years, only the results for 1998 are presented here. Because the ozone season of 1998 was the worst on record, the year provides a potentially rich data set for ozone modeling – and potentially several episodes that are representative of current design values.

The selection of the ozone episode for 1998 was a multi-step process. Design values were calculated for each monitor in South Carolina for 1998, by averaging the 4th highest ozone values from each of the years 1997, 1998, and 1999. If the design value of any monitor was less than 75 ppb, (10 ppb below the standard) the monitor was excluded from the analysis. All monitors had design values greater than 75 ppb. Design values for 1997-1999 are presented in Table 1-4.

Table 1-4.
1997-1999 design values for South Carolina monitoring sites used for 75 ppb screening test.

Monitor	1997-1999 DV	Monitor	1997-1999 DV
Army Reserve	79	Indiantown	73
Ashton	82	Jackson	89
Barnwell	88	Long Creek	86
Bushy Park	78	North Spartanburg	94
Cape Romain	75	Parklane	92
Chester	91	Pee Dee	88
Clemson	90	Powdersville	95
Congaree Swamp	73	Sand Hill	90
Cowpens	93	Trenton	85
Delta	84	York	86
Due West	86		

The top 8-hour ozone concentrations for each of the years 1997 – 1999 were also identified and averaged, for comparison purposes. All 8-hour ozone concentrations within approximately 10 ppb of the design value at each monitor were identified. Table 1-5 shows the range of values noted at each monitor. Dates with 8-hour ozone concentrations within the given range were selected for modeling purposes. Once these dates were selected, they were classified by meteorological conditions, with emphases on the wind parameters.

Table 1-5.
Range of values within 10 ppb of
the 4th highest 8-hour ozone concentration at each site.

Monitor	Range	Monitor	Range
Army Reserve	69 – 89	Indiantown	63 – 83
Ashton	72 – 92	Jackson	79 – 99
Barnwell	78 – 98	Long Creek	76 – 96
Bushy Park	68 – 88	North Spartanburg	84 – 104
Cape Romain	65 – 85	Parklane	82 – 102
Chester	81 – 101	Pee Dee	78 – 98
Clemson	80 – 100	Powdersville	85 – 105
Congaree Swamp	63 – 83	Sand Hill	80 – 100
Cowpens	83 – 103	Trenton	75 – 95
Delta	74 – 94	York	76 – 96
Due West	76 – 96		

Seven ozone episodes were selected and examined for the 1998 season. The episode of 15 – 22 May is presented here. Dates in bold italics in Table 1-6 represent days for which the maximum 8-hour ozone levels were within 10 ppb of the design values for the given monitor. The table divides South Carolina into four regions (Coastal, Midlands, Upstate, and Central Savannah River Area or CSRA). This helps to identify the regional impact of the ozone episode. Note that all areas were impacted by this early season event. During this period, a stagnant, flat upper-ridge was centered over the Gulf of Mexico, and extended northward into the Deep South and Southeast. This position of the upper-high cut off the moisture from the Gulf of Mexico, and resulted in unseasonably hot and dry weather in South Carolina.

The final step in the selection of ozone episodes was to classify the days from Table 1-5 by wind speed and direction. Table 1-6 lists examples of classification for two monitors during this May episode. On 16 May, the maximum 8-hour average ozone concentration at Army Reserve was within 10 ppb of the standard, with a wind speed of 5 mph from the south-southwest. On 18 May, the average was within 10 ppb of the design value and exceeded the 8-hour ozone standard, but the winds were from the east-southeast at 7.9 mph. These data yield a variety of different wind directions and wind speeds, thus satisfying the EPA guidance.

Table 1-6 also shows, for each region and over all monitors, the percent of monitors for which a given day had maximum 8-hour ozone within 10 ppb of that monitor's design value. During each of the days in 18 – 22 May, over 50% of all monitors met this criteria. Therefore these days were identified as key days, and selected to define the episode for future air quality modeling. On these days, 67, 81, 67, 62, and 52 percent of the monitors respectively, recorded 8-hour ozone concentrations within 10 ppb of the monitor design value.

Table 1-6.
Episode days with 8-hour ozone values within 10 ppb of the design value at a given monitor (bold italics). Percentages (shaded) represent monitors for region meeting criteria for given day.

Monitor	Date							
Cape Romain	15-May	16-May	17-May	18-May	19-May	20-May	21-May	22-May
Army Reserve	15-May	***16-May***	***17-May***	***18-May***	***19-May***	***20-May***	***21-May***	***22-May***
Ashton	***15-May***	***16-May***	17-May	***18-May***	***19-May***	***20-May***	***21-May***	***22-May***
Bushy	15-May	***16-May***	17-May	***18-May***	***19-May***	***20-May***	***21-May***	***22-May***
Indiantown	***15-May***	***16-May***	17-May	***18-May***	19-May	***20-May***	***21-May***	***22-May***
Coastal %	**40%**	**80%**	**20%**	**80%**	**60%**	**80%**	**80%**	**80%**
Sandhill	***15-May***	***16-May***	17-May	18-May	***19-May***	***20-May***	***21-May***	22-May
Parklane	***15-May***	16-May	17-May	18-May	***19-May***	***20-May***	21-May	22-May
Congaree	15-May	16-May	17-May	18-May	***19-May***	***20-May***	***21-May***	***22-May***
Pee Dee	15-May	***16-May***	17-May	***18-May***	***19-May***	20-May	***21-May***	22-May
Midlands %	**50%**	**50%**	**0%**	**25%**	**100%**	**75%**	**75%**	**25%**
Chester	***15-May***	16-May	17-May	***18-May***	***19-May***	***20-May***	***21-May***	22-May
Clemson	15-May	16-May	17-May	***18-May***	***19-May***	20-May	21-May	***22-May***
Cowpens	***15-May***	16-May	17-May	***18-May***	***19-May***	***20-May***	21-May	22-May
Delta	15-May	16-May	17-May	***18-May***	***19-May***	***20-May***	***21-May***	22-May
Due West	15-May	16-May	17-May	***18-May***	***19-May***	***20-May***	***21-May***	***22-May***
Longcreek	15-May	16-May	17-May	18-May	***19-May***	20-May	21-May	22-May
N Spartanburg	***15-May***	16-May	17-May	***18-May***	***19-May***	***20-May***	21-May	22-May
Powdersville	15-May	16-May	17-May	***18-May***	19-May	20-May	21-May	***22-May***
York	15-May	16-May	17-May	***18-May***	***19-May***	***20-May***	***21-May***	22-May
Upstate %	**33%**	**0%**	**0%**	**89%**	**89%**	**67%**	**44%**	**33%**
Barnwell	***15-May***	16-May	17-May	***18-May***	***19-May***	20-May	***21-May***	***22-May***
Jackson	15-May	16-May	17-May	18-May	19-May	***20-May***	***21-May***	***22-May***
Trenton	15-May	16-May	17-May	18-May	***19-May***	20-May	21-May	***22-May***
CSRA%	**33%**	**0%**	**0%**	**33%**	**67%**	**33%**	**67%**	**100%**
Total %	**38%**	**29%**	**5%**	**67%**	**81%**	**67%**	**62%**	**52%**

Table 1-7.
Wind speed (Ws) and wind direction (Wd) for selected monitoring sites for key days of the May 1998 episode period.

Ashton	Ws	Wd	Bushy Park	Ws	Wd
5/18/98	7.9	70	5/18/98	7.9	70
5/19/98	5.5	120	5/19/98	5.5	10
5/20/98			5/20/98	9.1	240

As indicated in Table 1-6, the days listed in Table 1-7 are key days with ozone concentrations within 10 ppb of the site-specific design value.

Findings from a Related Study

Results from a recent episode selection analysis designed to identify historical ozone episode periods suitable for use in conducting analysis and modeling activities related to 1-hour and 8-hour ozone for potential nonattainment areas in the northern portions of Georgia and Alabama (Douglas et al., 1999) were examined to see if the SC DHEC episode days were also chosen using a different approach for neighboring areas. The methodology used for this other episode selection analysis was based on that developed for the Southern Appalachian Mountains Initiative (SAMI) episode selection study by Deuel and Douglas (1998). Days within the analysis period 1990-1998 were classified according to meteorological and air quality parameters using the Classification and Regression Tree (CART) analysis technique. The frequency of occurrence of ozone exceedances for each classification type was then determined for each of the areas of interest. Days with maximum ozone concentrations within approximately 10 ppb of the respective design values were also identified. Finally, an optimization procedure was applied to the selection of multi-day episodes for maximum achievement of the specified episode selection criteria, outlined above, for various combinations of geographical areas and ozone metrics (i.e., 1-hour and 8-hour ozone).

Results for the Atlanta area do not indicate that these episode days represent typical meteorological/ozone exceedance regimes for the Atlanta area. However, 8-hour ozone concentrations greater than 100 ppb were recorded at one or more of the Atlanta-area monitoring sites on all five days, with a maximum 8-hour value of 125 ppb on 19 May.

Results for the Augusta, Georgia area (located along the Georgia/South Carolina border) were also examined. Of the five May 1998 South Carolina episode days, three days, 19 – 21 May, were classified as representative of frequently occurring meteorological/ozone exceedance regimes. Maximum 8-hour ozone concentrations greater than 85 ppb were recorded on four of the five days (19-22 May), with a maximum 8-hour value of 105 ppb on 20 May.

The finding for Augusta from this alternative episode selection analysis indicates that the period of 18 – 22 May is valid for modeling purposes. The data for August and Atlanta suggest that ozone exceedance was a regional event and that there is some potential for regional-scale transport.

Other Considerations

For the purposes of identifying certain meteorological regimes that led to the ultimate selection by DHEC of the May 16-23, 1998 episode, EPA draft guidance was applied to the unique climatology found across the state of South Carolina. The recommendations were then sent to SAI for further analysis. Their analysis confirmed the viability of the May 16-23, 1998 episode for South Carolina's Urban Airshed Model applications. Following both analyses, DHEC performed a third analysis to thoroughly evaluate the episode choice along side a number of other potential time periods (from 1997 through 2000). This third analysis found the May 1998 event to be the most representative example of various causes of elevated ozone in our areas of concern: stagnation, recirculation, and transport.

The methodology evaluating these processes from a strictly synoptic meteorological point of view is not an easy task. Paramount in attempting to correlate elevated ozone with raw climatology is the realization that most processes involved are directly related to, though not entirely caused by, changes in wind speeds and directions. They are also not confined strictly to the surface as they are more often than not largely affected by meteorology extending well above the planetary boundary layer (PBL). Unfortunately, instrumentation does not yet exist in a spatial resolution adequate enough to gain the most ideal synopsis of wind characteristics across an area as large as nearly three-fourths of the State of South Carolina. Therefore, steps were taken in this study to extrapolate the overall flow of the episode from start to finish through the three aforementioned causes of elevated ozone throughout this period. As noted in Table 1-8 below, the selected episode can be reliably divided into 6 distinct "regimes", intuitively interpreted from existing observational data and model output. This summary will highlight the significance of each of these six periods to the identification of the May 16-23, 1998 episode as the proper choice for regional scale attainment modeling in South Carolina.

Table 1-8.
Progression of meteorological regimes for the 1998 modeling episode.

Period	Timeframe	Wind Field Characteristics
1) Background	5/16 thru 5/17	Starting out southerly, and of moderate speeds, then veering more southwesterly thru period ahead of approaching back door front.
2) Buildup	5/17 thru 5/18	Gradual veering more westerly, then sharp northeasterly behind weak back-door frontal boundary passing through.
3) Stagnation	5/18 thru 5/19	Backing more easterly as front dissolves, then becoming light & variable (<5 kt) as core of mesohigh in weak wind field moves over.
4) Recirculation	5/19 thru 5/20	Slow veer around to more SW as ridge expands. Winds very light initially (~5kt), but gradual pick up of speed as main anticyclonic circulation moves off the GA coast.
5) Transport	5/20 and 5/21	Moderate SW transport to west of lee-side trof over Upstate region. Becomes almost due westerly as lee trof strengthens with added subsidence from building ridge aloft.
6) Cleanout	5/22 and 5/23	Sharp veering over lower state back to moderate easterly flow as next back-door front moves in and orients N-S. Mesolow moves over, resulting in a sharp veer to moderate southerly flow statewide thru end of event.

The Background period, denotes the initial state of the wind field at the beginning of the modeling episode (00z 16-MAY-1998), while a fairly normal early summer-like pattern was set up over the Southeastern US. At this point, surface analysis (figure 1-4a) showed a weak surface ridge across the state. Winds were, for the most part, southerly at 8-10 knots across the areas of concern for the modeling project (figure 1-4c). With upper-level ridging (figure 1-2b) over the Gulf Coastal states, there was a trend towards mid-level subsidence on a moderate NW flow aloft. As such, a lee-side thermal trough had formed over the Upstate region, with a good sea breeze front along the coast indicative of a strong thermal gradient set up between sea-surface temperatures only in the 70s, with those over inland areas up to 20 degrees warmer. With such a buoyant atmosphere, the mixed layer in the PBL gradually rose, with convection currents causing a number of small scale anticyclonic eddies scattered about the area at random.

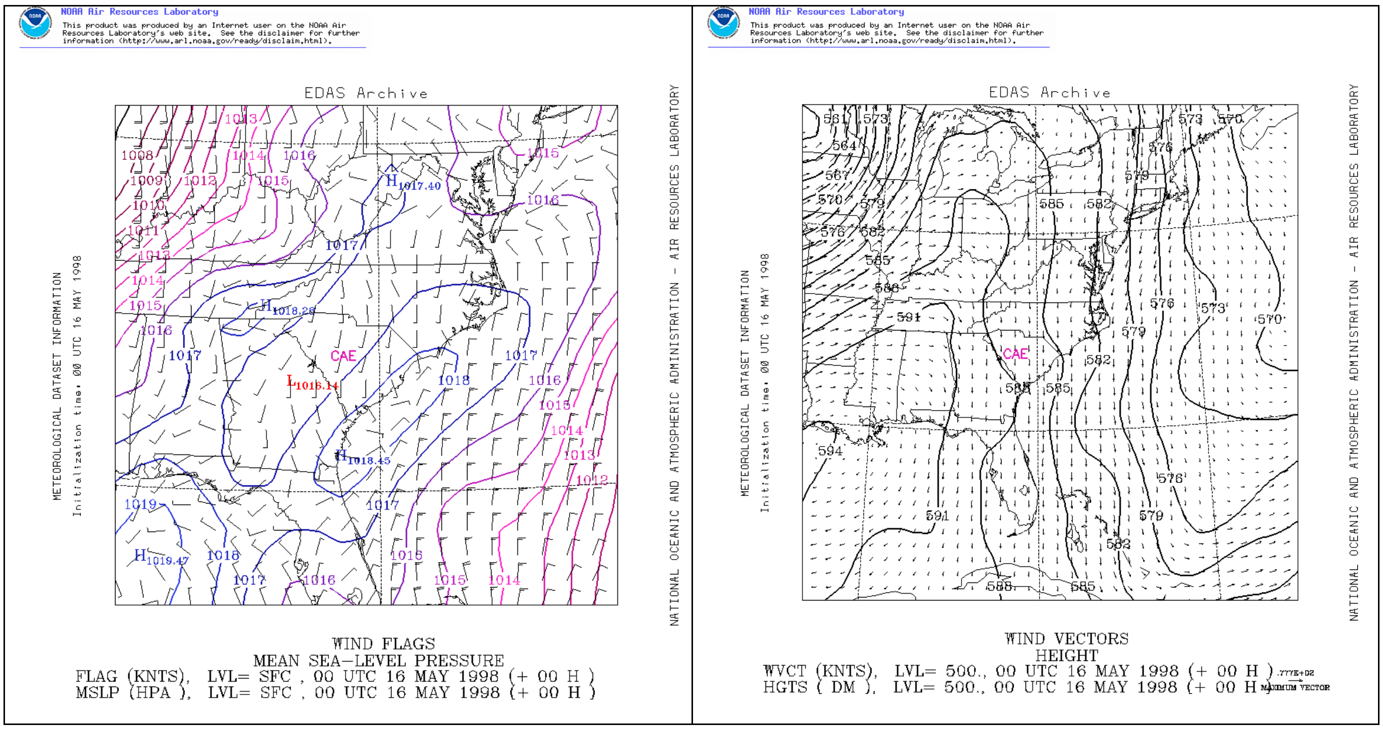
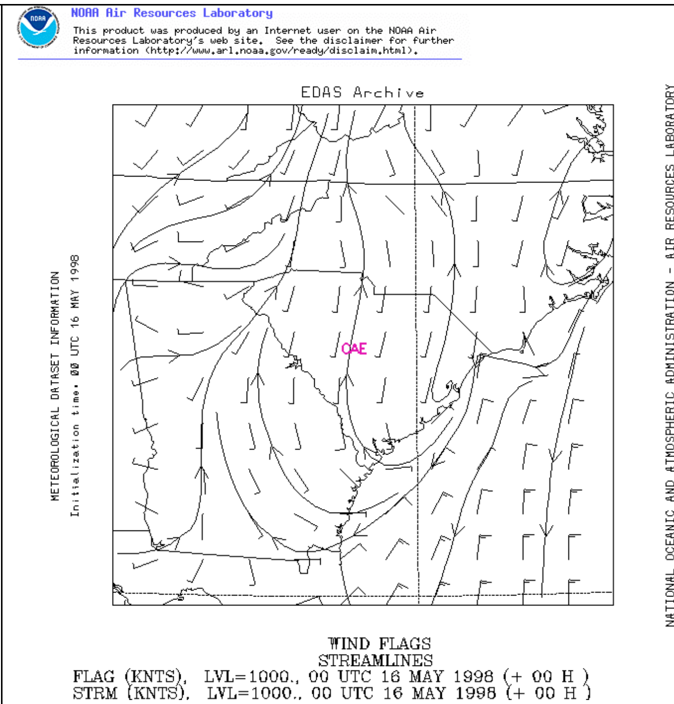


Figure 1-4a-c Synoptic Features, Background Period

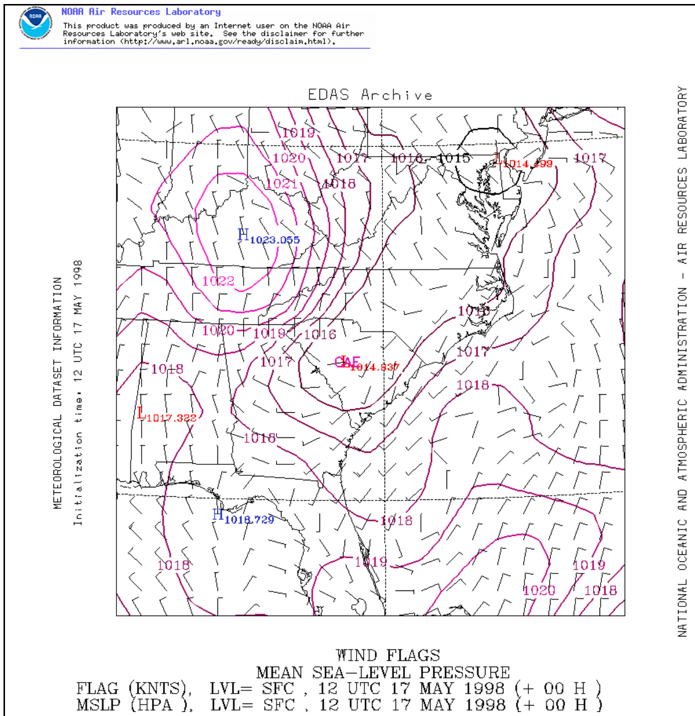
Figure 1-4a (above), 1000mb analysis: In weak pressure field of overall ridging, weak lee-side trof exists over central SC, with a number of mesohighs: over the spine of the Appalachians, off the Gulf Coast of FL, and along the Atlantic Coast of SC & GA.

Figure 1-4b (above right), 500mb analysis: SC influenced mainly by interaction between large 591dm ridge centered over Central Gulf Coastal states, and 568dm trof extending into Atlantic just north of Bermuda.

Figure 1-4c (lower right), 1000mb streamlines: Shows light southerly flow across most of SC, with broad lee trof from Piedmont to Coastal sections. Winds converging over extreme Upstate region denote formation of a more synoptically forced pre-frontal trof ahead of back-door front (becoming increasingly diffuse over Appalachians).



The ***Buildup*** period began through the early morning hours on 17 May, with the approach of a shallow back-door cold front becoming diffuse as it passed over the rough terrain of the Appalachians of Western NC (figure 1-5a). Little support existed by this time in the upper levels for large-scale synoptic movement of such a shallow air mass (figure 1-5b). Though winds increased and aligned themselves more southwesterly ahead of this boundary, they eventually began to lighten in the subsidence zone east of the trof associated with the main convergence boundary of the front. By the afternoon of the 17th, this boundary had clearly lost momentum, with light-and-variable (LV) winds, defined as winds below 5 knots in this case, to the east of the trof situated across the Pee Dee and Midlands areas of the state. This allowed for increased low-level subsidence along and behind the main frontal boundary (figure 1-5c).



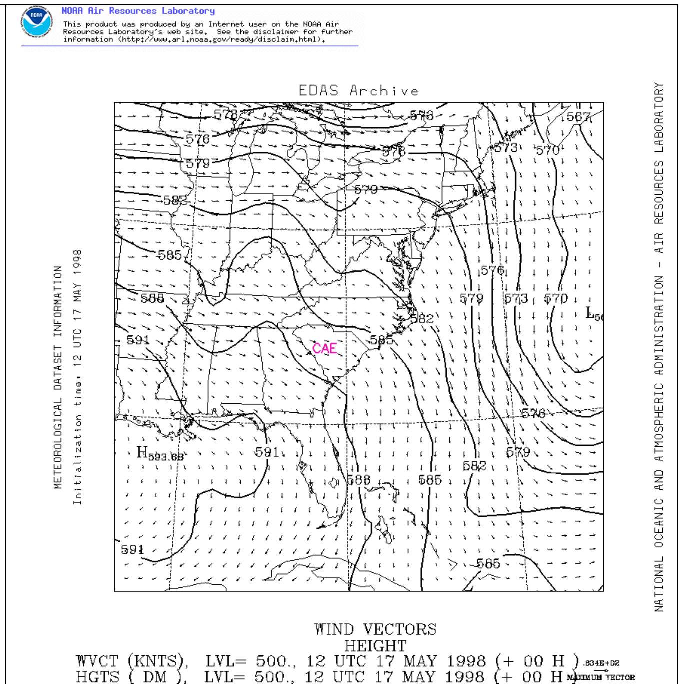
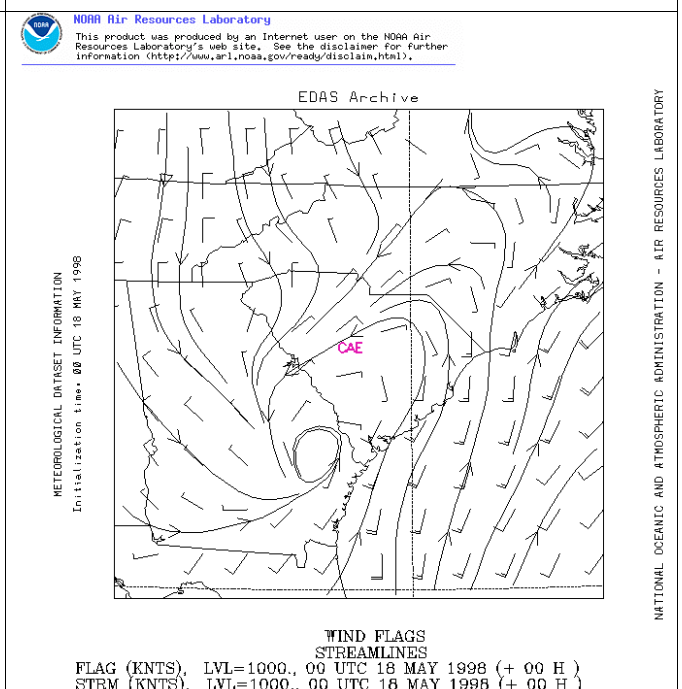


Figure 1-5a-c Synoptic Features, Buildup Period

Figure 1-5a (above), 1000mb analysis: By the morning of 17 May the back-door front was now wedging across the breadth of SC with a significant surface ridge poised to build rapidly southeast as the front dissipates.

Figure 1-5b (above right), 500mb analysis: Mesoscale ridge axis is now to the west, building over core of surface ridge. With flow aloft now oriented northwesterly, this "stacked" ridge should be able to build all the way across SC in time.

Figure 1-5c (lower right), 1000mb streamlines: Southerly flow now veering around more southwest ahead of diffuse frontal boundary, with very light & variable (<5kt) flow in the zone of subsidence to the west of the boundary. This flow will continue to veer ahead of the building ridge on 18 May, the net result being northeasterly winds across the majority of the state.



With the front rapidly losing momentum and the upper-ridge now consolidated all the way from the Atlantic Seaboard back into the Mississippi Valley, the surface high once pushing the front began to build over the state on a steady NW flow aloft (Figure 1-6a-b). By the afternoon on 17 May, winds behind the dissipating boundary had begun a progressive shift around to northeasterly around 8-10 knots. They then diminished to dead calm overnight as a small anticyclonic eddy ("mesohigh") built across the entire state (Figure 1-6c). This marked the onset of the "stagnation" period, characterized by the continued buildup of a pool of ozone precursors across a wide area into the afternoon of 19 May. Due to near perfect production conditions (little horizontal motion, high mixing heights, temps in the low 90s w/near 100% insolation, low afternoon relative humidity, and subsiding vertical motion aloft), this pool would provide the basis for the onset of the peak two days of the ozone event.

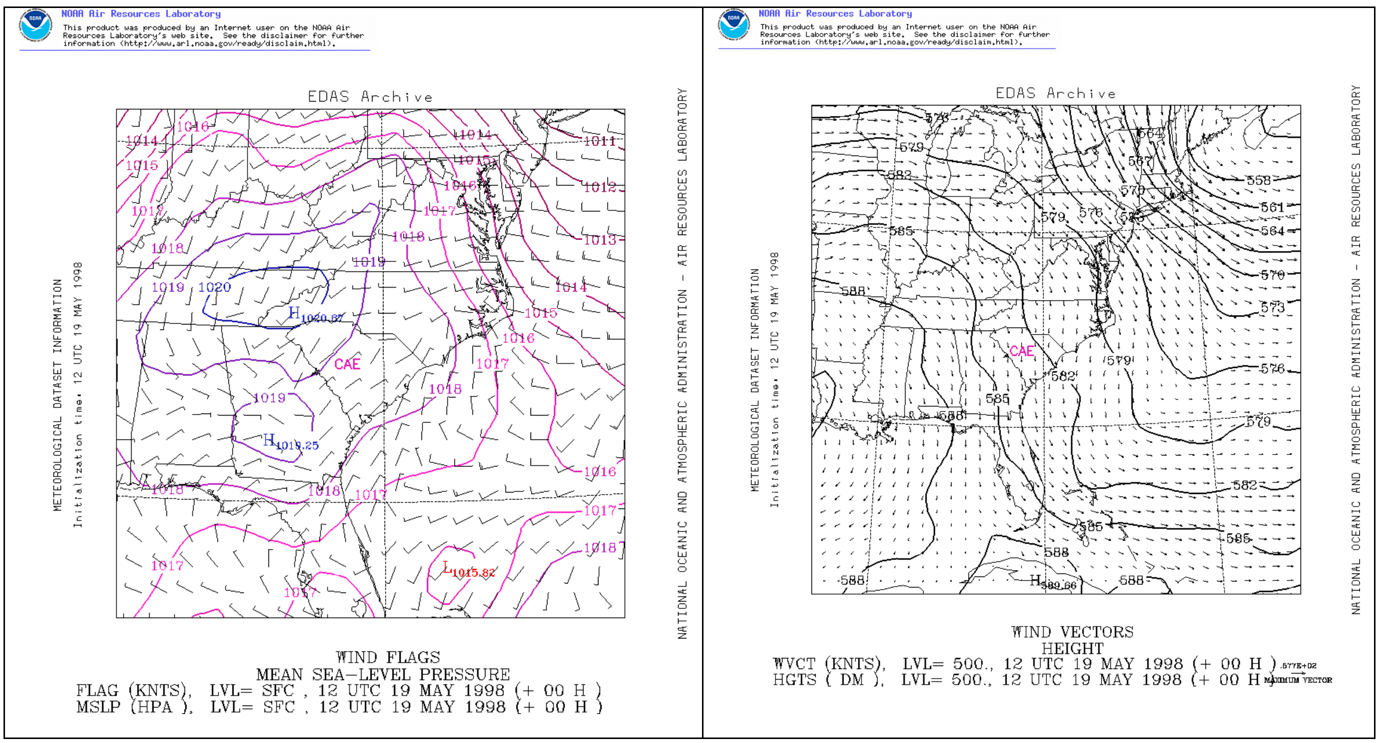
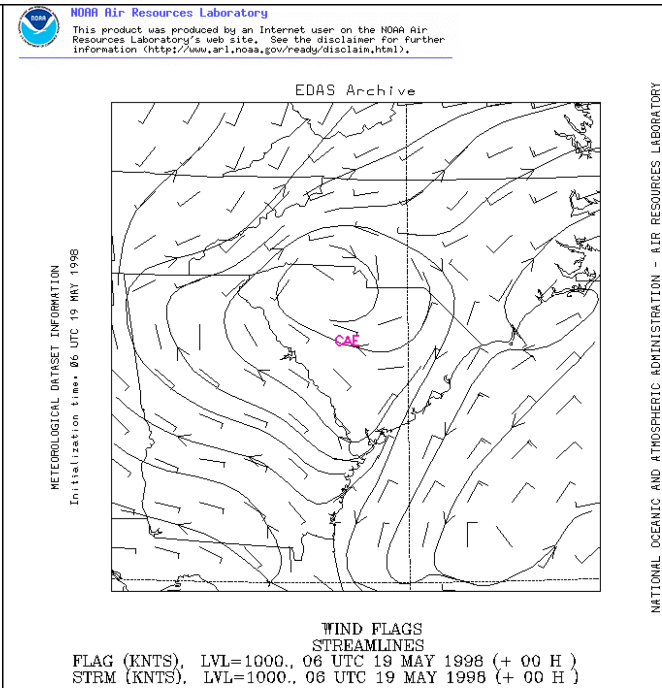


Figure 1-6a-c Synoptic Features, Stagnation Period

Figure 1-6a (above), 1000mb analysis: The ridge had just about built across the entire interior Southeast, with no trace of the back-door front or its now filled-in trof. The pressure gradient is now so weak, that the pattern is susceptible to a great deal of variation in trajectories within the wind field.

Figure 1-6b (above right), 500mb analysis: The overall expansion of the ridge has shifted into the Central and Northern Plains. Though geopotential heights are lower than the previous day, the trof to the east is also weaker. Thus, a broad zone of negative vorticity continues to advect (NVA) into the Carolinas, enhancing subsidence aloft, and providing an ideal atmosphere for maximum incoming UV radiation.

Figure 1-6c (lower right), 1000mb streamlines: The overnight period of 18 – 19 May was marked by a mesohigh that broke off and traversed SC from NW to SE. As the pressure field further weakened under this anticyclone, winds nearly died out across two thirds of the state.



The ***Recirculation*** period began in the early afternoon of 19 May as the core of the surface high moved off the Atlantic Seaboard, with winds beginning to increase on the north and west side its core (Figure 1-7a). With a continuation of subsiding air aloft, vertical mixing in the PBL remained inhibited. Thus, precursors that had begun pooling in the lower atmosphere since 18 May were unable to disperse. With the axis of the surface ridge continuing to pull offshore, the entire air mass began to spread west into Georgia. A low-level jet of 10-12 knots then began to set up just to the east of the Blue Ridge. By the time this flow became mature and the transport period of the event began, the air mass had effectively recirculated over its initial source areas, only to pick up more precursors (Figure 1-7b).

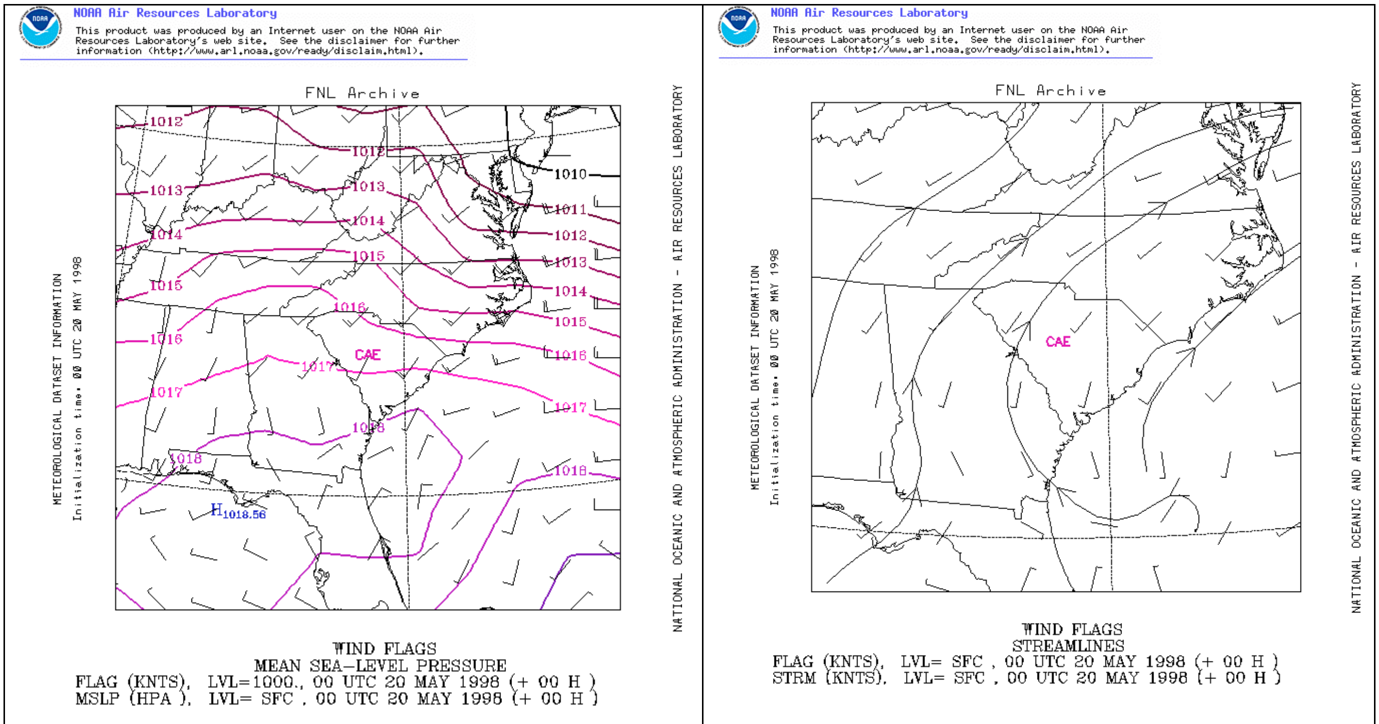
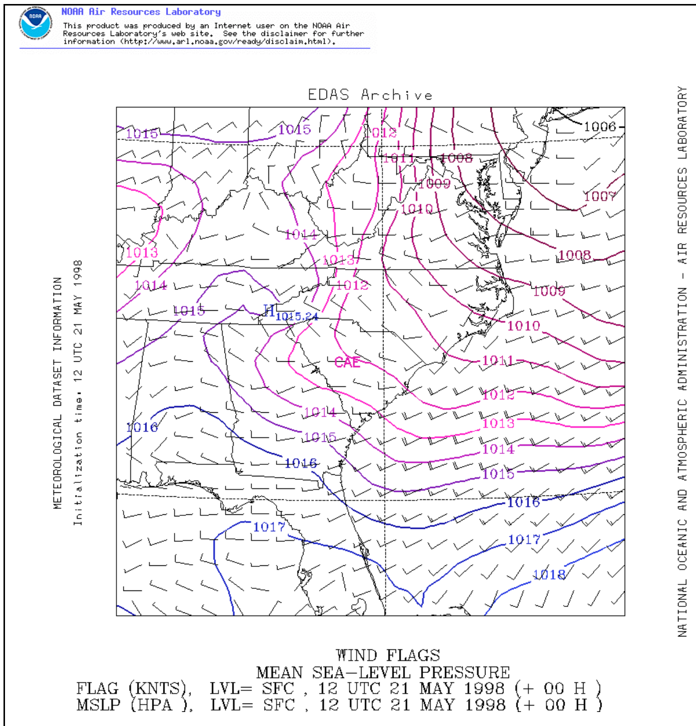


Figure 1-7a-b Synoptic Features, Recirculation Period.

Figure 1-7a (above left), 1000mb analysis: The core of the surface high consolidates as it moves offshore, flattening out to the west along the Northern Gulf Coast. The pressure gradient strengthening slightly, winds began a slow pickup in speed.

Figure 1-7b (above right), Sfc streamlines (no 1000mb available): Winds have picked up 5-8 knots from the south and southwest, the opposite direction as the day before. Air mass trajectory is now out over Central then Northern GA, then back towards Upstate SC.

By the afternoon of 20 May, the low-level jet along the Blue Ridge had fully matured, topping out around 12 knots to the north of the I-85 corridor. With upper-level conditions virtually unchanged for the past 3 days, the recirculated air mass began to move and expand. It initially did so to the west, then eventually to the north, before finally getting caught up in the flow along the lee of the Appalachians, which sent the whole pool back to the Northeast. The mixing scheme within the air mass was becoming increasingly suppressed as a trough began to develop in the Midlands and Upstate of SC, on the lee (east) of the Blue Ridge (Figure 1-8a). Open to upwind sourcing from urban areas to the west of SC, additional precursors entered the already polluted air mass. This period of ***transport***, the longest such period of the event, occurred in two distinct phases. The first, *southwesterly* transport, affected mainly the Upstate of SC through the afternoon on 20 May (Figure 1-8b). The second phase was marked by a fairly consistent period of 8-10 knot *westerly* winds from late afternoon on 20 May through the end of peak ozone hours on 21 May, affecting areas around Augusta, GA and Aiken, SC (Figure 1-8c). As this period of transport began to wind down overnight on 21 – 22 May, the flow had been consistent from a general southwest or westerly direction for a full 30-36 hours.



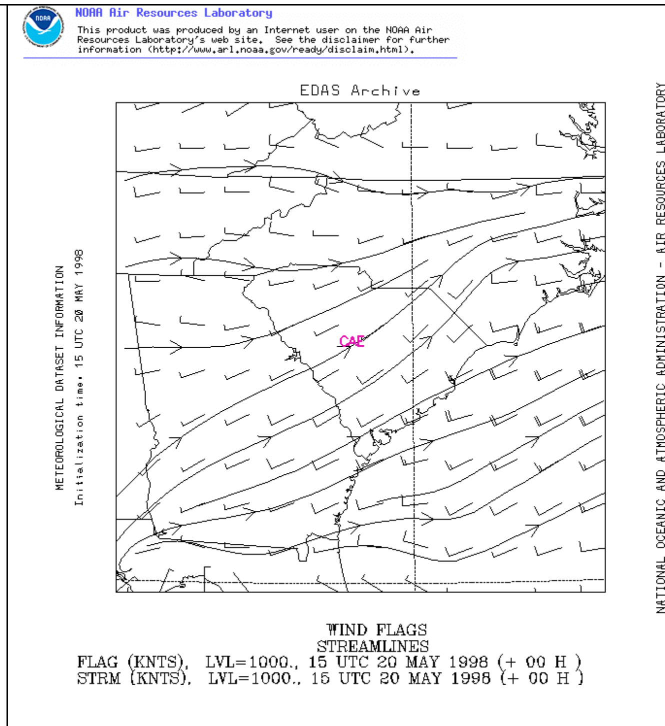
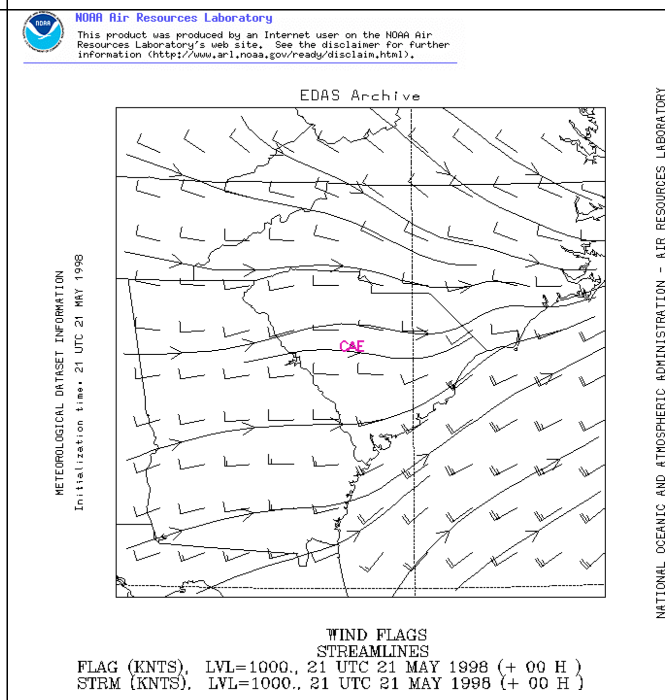


Figure 1-8a-c Synoptic Features, Transport Period.

Figure 1-8a (above), 1000mb analysis: A moderate low-level jet on 19 and 20 May gave way to a strong down-sloping westerly flow on 21 May. A strong lee-side trough developed, perpetuating this flow, aided by the flat surface ridge that had moved to the south of the Carolinas.

Figure 1-8b (above right), 11am 1000mb streamlines, 20 May: The southwesterly transport was most pronounced as the day progressed on 20 May. Wind speeds were nearly consistent around 10 kt across the entire Upstate region.

Figure 1-8c (lower right), 5pm 1000mb streamlines, 21 May: The downsloping flow during the peak ozone hours of 21 May spread across the entire length of the SC/GA border along the Savannah River. Even with wind speeds now up to 12-15 knots in some places, ozone readings in the Aiken / Augusta area soared.



The cleanout period began as the upper-level ridge that had been so persistent to the west had finally over extended itself by 22 May, breaking down into a rather broad ridge / trough pattern (Figure 1-9b). Sinking air aloft was now replaced by a more neutral advection pattern, with a series of weak waves moving through the flow providing brief bursts of enhanced vertical motion. Additionally, these disturbances combined to nudge another back-door cold front into SC, albeit briefly (Figure 1-9a). The flow aloft became zonal on 23 May, with the back-door front moving back into North Carolina as a warm front (Figure 1-9c). However, by then, winds, now around 10 knots out of a general southerly direction, had already pushed most ozone residuals northward out of SC. Dispersion was now able to occur over a wide area, hampering ozone production locally and upstream, effectively ending the episode.

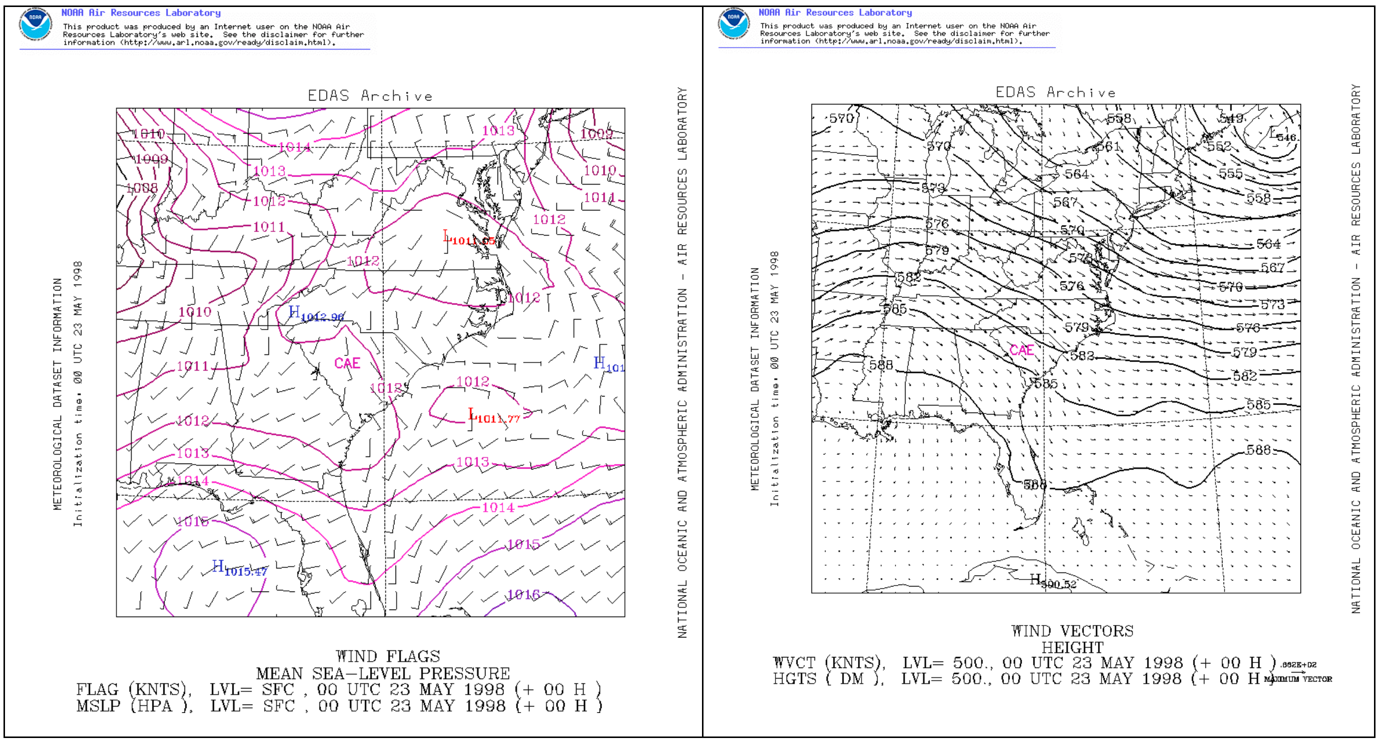
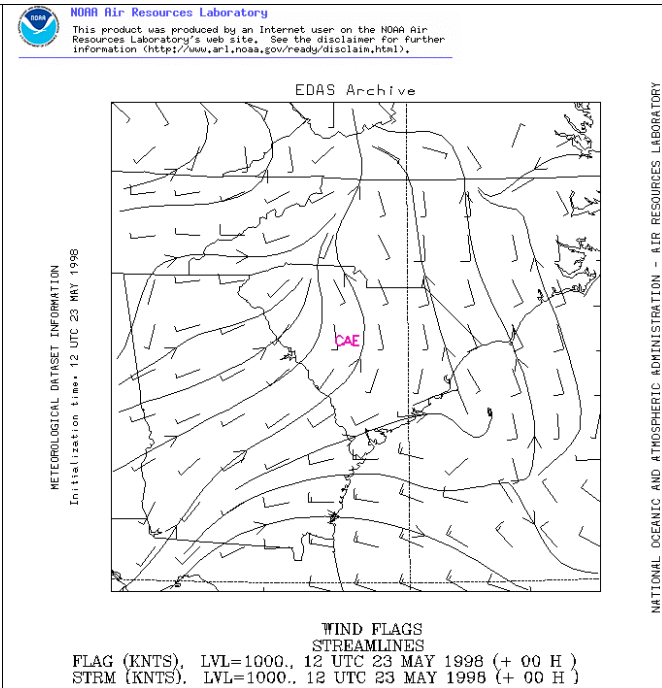


Figure 1-9a-c Synoptic Features, Cleanout Period.

Figure 1-9a (above), 1000mb: Weak ridging now effectively replaced by a trof in the vicinity of a weak back-door cold front. Winds that had been steady out of the west for nearly two days were now responding to the change in pressure field, backing to a more southerly direction.

Figure 1-9b (above right), 500mb: The ridge over the Mississippi Valley had now broken down and broadened along the Gulf Coast. A number of pockets of short-wave energy are now apparent in the flow, each providing a brief period of positive vorticity advection (PVA), helping to lift and mix the air vertically.

Figure 1-9c (lower right), 1000mb streamlines: By the morning of 23 May, the back-door front was on its way back northward out of SC, pushed along by a fairly steady ten knot southerly flow.



In order to make certain potential ozone episodes were properly evaluated prior to their selection for modeling purposes, meteorologists at SC DHEC felt the basic EPA guidance, as drafted, required expounding upon in order to determine the ideal episode to model. Towards this goal, independent studies were completed by both DHEC and SAI, each designed to fully evaluate the episode period suspected to be the best fit for attainment modeling purposes. The first two studies show this to be true.

However, South Carolina has, as does every distinct geographic area, its own unique climatology, whose analysis cannot be easily condensed into uniform rules of interpretation. As such, this third and final study was performed. In breaking down each potential episode to smaller units of time, and using the best available synoptic tools in the analysis, the ultimate selection of the proper episode to model became a much more reliable and definitive process. The third analysis also showed the May 16-23, 1998 episode to be the best modeling period available for use in the Bureau's UAM-V modeling project.

A typical modeling episode periods includes 2 to 3 start-up days, during which the influence of the initial conditions, which are not well known, is expected to be greatest, and one clean out day, used for model evaluation purposes to ensure that the model is able to simulate both higher and lower ozone concentration days. It is also desirable to initiate the simulation when the ozone concentrations are relatively low, so that day-to-day ozone carryover from the start-up days to the primary days is minimized. This is particularly important if the concentrations for the start-up days are not accurately simulated.

Based on a review of the ozone data for sites in South Carolina, as well as for Atlanta and Augusta, the recommended modeling period is 16 – 23 May. This eight-day period begins and ends on a Saturday. Thus all key modeling days are weekdays.

Summary

In summary, the 16 – 23 May 1998 period provides a good basis for modeling for all four areas, for the objectives of capturing multiple high ozone days and some different wind directions for the South Carolina monitoring sites. The key modeling days are 18 – 22 May. The episode provides a good episode for modeling because several different areas of the state are affected, thus allowing an evaluation of the emissions inventory as well as the ability of the modeling system to replicate the observed ozone concentration patterns and levels. The results of the methodology used for this analysis were backed by results from a related study done for the Augusta area in neighboring Georgia.

F. Meteorological and Air Quality Characteristics of the Modeling Episodes

Meteorological and Air Quality Characteristics of the Modeling Episode Period

The modeling episode period includes eight days that, in accordance with the episode selection goals, represent a range of meteorological and air quality conditions within South Carolina. The characteristics of the simulation period are described in this subsection of the report. The episode days are also intended to represent those conditions that most frequently accompany ozone exceedances in the areas of interest. Thus, we begin this section with a brief discussion of the key factors that influence ozone concentrations within South Carolina and the areas of interest.

Conceptual Model of Ozone Formation

Ozone episodes for many areas in the U.S. are often characterized relative to regional-scale meteorological high- and low-pressure patterns and specifically the presence of a surface-based high-pressure system (an area over which the atmospheric pressure is relatively higher than the surrounding areas). The location of the high pressure system relative to the area of interest determines the prevailing wind and dispersion conditions and thus the source-receptor relationships that characterize an ozone episode, whereas the persistence and strength of the system influence/determine episode severity. A textbook depiction of an ozone episode places the high-pressure system over an urban area. This results in suppressed vertical mixing of emissions/pollutants, low wind speeds or stagnation, low humidity, high temperatures, clear skies, and strong solar insolation. These are the typical ingredients of an ozone episode.

The “recipe” for high ozone concentrations varies throughout the U.S. according to geographical characteristics, local and regional emissions characteristics, and the location of each area relative to other areas in combination with pollutant-transport-conducive meteorological conditions. The complexity of any conceptual model for ozone formation increases with each of these factors.

Somewhat counter to the typical characteristics of ozone episodes, experience has shown that many high ozone events in South Carolina occur in conjunction with weak troughs or frontal systems. One hypothesis as to why this occurs is that the vertical mixing generated by these disturbances enhances the entrainment of ozone from aloft into the surface layer, where the measurements are obtained. The high ozone aloft is attributable to regional-scale build up of ozone (i.e., day-to-day carryover) or transport.

High ozone events in South Carolina are also typically associated with regional-scale northerly or westerly wind components (i.e., winds from the continent). This is easily explained by the notion that wind directions from the ocean would typically bring cleaner air into the state.

While the synoptic weather patterns influence the formation and transport of ozone throughout the region, other factors also influence the ozone concentrations and concentration patterns. Superimposed on the synoptic and regional effects are the local effects that determine ozone concentrations at the various monitoring sites within South Carolina. The local factors vary from area to area within the state but generally include low wind speeds, which limits dispersion. The sea breeze also plays a role in establishing ozone concentration patterns along the coast, and further inland in some cases. The strength, timing, and inland extent of the sea breeze can determine whether sites located along the coast are within a zone of higher ozone, which often occurs along a sea breeze front, or whether they are influenced by the lower concentrations and enhanced vertical mixing that a well-established sea breeze can bring once the sea breeze front has moved further inland.

The May 1998 simulation period exhibits many of the typical characteristics of high ozone events in South Carolina. The specific meteorological and ozone air quality characteristics of the simulation period are summarized in the following subsections of the report.

Regional Scale Meteorology

In the following discussion, regional-scale meteorology for the modeling episode days is characterized by the location and movement of synoptic or regional-scale features (such as high and low pressure systems and fronts), prevailing wind directions, maximum temperatures within the region, and cloud-cover and rainfall characteristics.

Surface weather maps for the May 1998 modeling episode period show high pressure over the Southeast that is interrupted on two occasions by the passage (or setting up) of a weak trough or frontal system over South Carolina. The first of these moves across the state from northwest to southeast during 16 and 17 May. This is followed by high pressure over the east and southeast through approximately 21 May. The surface analysis for the 22nd shows an occluded front positioned across the state from west to east. This frontal system moves in from the North and appears to stall over the Southeast. It persists with some apparent movement to the North through the 23rd.

The 500 mb meteorological charts (approximately 5000 m above ground level (agl)) show persistent high pressure over the Gulf of Mexico throughout the simulation period. A high-pressure ridge is apparent along the east coast during the first couple of days of the simulation period. This is followed by a flattening of the high-pressure system over the Gulf of Mexico and a more zonal pressure pattern for the remainder of the simulation period. Winds at this level gradually back from northerly to westerly during the period.

Maximum temperatures in Charleston, Augusta, and Charlotte areas gradually increase through approximately 21 May, but are relatively high (in the upper 80s to low 90s in degrees Fahrenheit (°F)) on all of the modeling episode days. Except for the first day, there is little gradient in temperature across the state. Rainfall occurs in the northeastern part of South Carolina on the 17th and then again on the 22nd. In general, however, there is no significant rainfall for South Carolina during the modeling episode period.

The wind directions at upper levels (approximately 1000 m agl) vary throughout the period. Northwesterly winds on the 16th are replaced by a cyclonic circulation over the state on the 17th. This is followed by northeasterly winds at this level on the 18th that gradually become northwesterly by the 20th. Light and variable winds aloft on the 22nd reflect the presence of the occluded front across South Carolina on this day. Southeasterly winds aloft on the 23rd mark the end of the episode period. There is much variability in surface wind speeds and directions over South Carolina throughout this period.

In summary, the simulation period is influenced by both high pressure and weak low pressure troughs that appear on certain of the simulation days. Thus, a couple of different synoptic- or regional-scale pressure patterns are represented by the simulation period. In addition, wind directions vary throughout the period such that a variety of wind directions are captured; these include northerly, northeasterly, northwesterly, westerly, southwesterly, and light and variable/cyclonic wind directions/patterns.

Ozone Concentrations and Key Ozone Episode Days

No monitoring sites in South Carolina exceed the 8-hour NAAQS on 16 and 17 May. The following five days, 18 – 22 May, comprise the key ozone episode. For the first three of these days, exceedances occur within all five of the primary areas of interest: Aiken/Augusta, Anderson/Greenville/Spartanburg, Columbia, Florence/Darlington, and Rock Hill. The Columbia area continues to have sites in exceedance of the 8-hour ozone NAAQS on 21 and 22 May. On 21 May, Rock Hill and Florence/Darlington also have sites in exceedance of the NAAQS; on 22 May, an exceedance occurs in the Anderson/Greenville/Spartanburg area. In the southern part of the state, the Ashton monitoring site has peak 8-hour ozone values above the NAAQS from 19 – 22 May, but these values are lower than those for most of the other South Carolina sites in exceedance on those days.

The statewide peak 8-hour ozone concentration occurs in the Anderson/Greenville/Spartanburg area on 18 May, and in the Columbia area for the rest of the ozone episode, 19 – 22 May. From 19 – 21 May, exceedances also occur in nearby Augusta, GA, but these values are lower than those for the Aiken area. However, throughout the episode, peak values in the Atlanta, GA area are consistently higher than all other sites in the domain. While peak 8-hour ozone values for all of South Carolina range from 94 to 104 ppb during the episode, peak values in the Atlanta, GA area range from 103 to 125 ppb. Exceedances also occur in the area of Charlotte, NC from 18 – 21 May; peak values on these days range from 88 to 105 ppb. These values are presented in Table 1-8 below.

May 19 and 20 stand out as days with exceedances all throughout the domain: in all four areas of interest in South Carolina, as well as in Charleston, Atlanta, Augusta, and Charlotte. Eight-hour ozone is especially high in Atlanta on the 19th, with four monitoring sites exhibiting peak ozone values of 105 to 125 ppb. While exceedance occurs at many sites on 21 and 22 May (especially in the Columbia area), peak ozone values in general decline over these two days. By 23 May, no monitoring site in the domain exceeds the NAAQS.

Table 1-9.
Maximum 8-hour ozone values in selected regions of the domain for key episode days.

	18 May	19 May	20 May	21 May	22 May
South Carolina	100	101	104	94	95
Location of Peak:	**Clemson, SC**	**Jackson, SC**	**Trenton, SC**	**Barnwell, SC**	**Jackson, SC**
Augusta, GA	82	92	99	94	78
Atlanta, GA area	108	125	105	104	103
Charlotte, NC area	93	101	105	88	74

Emissions Influencing Ozone within South Carolina

All of the South Carolina EAC areas are located in the Southeast portion of the continental U.S. Regional scale modeling results performed by EPA (e.g., EPA, 2004) as well as the modeling results presented later in this report indicate that ozone concentrations in this region are influenced by ozone and precursor transport from outside of the region. Emission source areas to the north, west, and south including major metropolitan areas to the northeast, north, and west of the domain ensure the potential for a contribution from regional-scale transport. As indicated in a previous section, ozone episodes are associated with a variety of upper-level wind directions and, thus, a range of potential transport conditions.

Within the region, there are numerous sources of NO_x, VOC, and CO emissions that likely also contribute to ozone production in the region and affect one or more of the EAC areas. Ozone precursor emissions from anthropogenic sources are the result of activity associated with transportation (both interstate and local), electrical generation, manufacturing/industry, and other population-related sources (household products, home heating, recreational equipment, etc.). A number of electrical generation stations, chemical industry sources, and gas compressor stations are located in the region. In addition, other sources such as manufacturing facilities contribute to the emissions totals in specific portions of the region.

Plots of the anthropogenic NO_x and VOC emissions by source category are presented for each EAC region in Figure 1-10. In general, large sources of NO_x include electric generation, other industrial boilers, and mobile sources. The anthropogenic VOC emissions originate from a variety of area, industrial, and transportation-related sources.

In addition to anthropogenic sources, South Carolina has a high percentage of VOC emissions from biogenic sources, which are emitted from the region's extensive hardwood and softwood forests, other natural vegetation and from various crops that are raised in the region. The biogenic emissions in South Carolina make up about 83 percent of the total VOC emissions on a typical summer day. The percentage of the total VOC emissions from biogenic sources on a typical summer day is somewhat less for the EAC areas and is 71% for the Columbia area and 68% for the Anderson/Greenville/Spartanburg area.

There is some slight variation in emissions day to day during a typical summer, with some decreases in mobile emissions expected on weekend days and corresponding increases in non-road emissions, likely associated with the usage of recreational equipment. The anthropogenic and biogenic precursor emissions are affected by local and regional weather conditions, which affect the formation, transport, and deposition characteristics of ozone concentrations within the region.

Emissions of NO_x are expected to decrease in the future due to the implementation of the NO_x SIP call along with tier II and low sulfur fuel standards for mobile sources. As indicated later in this document, South Carolina is primarily NO_x limited in ozone production so these NO_x reductions should help reduce ozone in the future.

G. Report Contents

The remainder of this document summarizes the methods and results of the SC DHEC 8-hour ozone photochemical modeling analysis. The modeling protocol is presented in Section 2. Preparation of the emissions inventory, meteorological, and other geographical/air quality/chemistry related inputs is summarized in Sections 3, 4, and 5, respectively. Model performance evaluation is discussed in Section 6. Future-year modeling and sensitivity analyses are discussed in Section 7. Application of the 8-hour ozone attainment demonstration procedures is presented and discussed in Section 8. Review procedures for the modeling analysis are described in Section 9. Archival and data acquisition procedures are outlined in Section 10.

Figure 1-10a. Anderson, Greenville, Spartanburg area NOx 1998 Episode Emissions

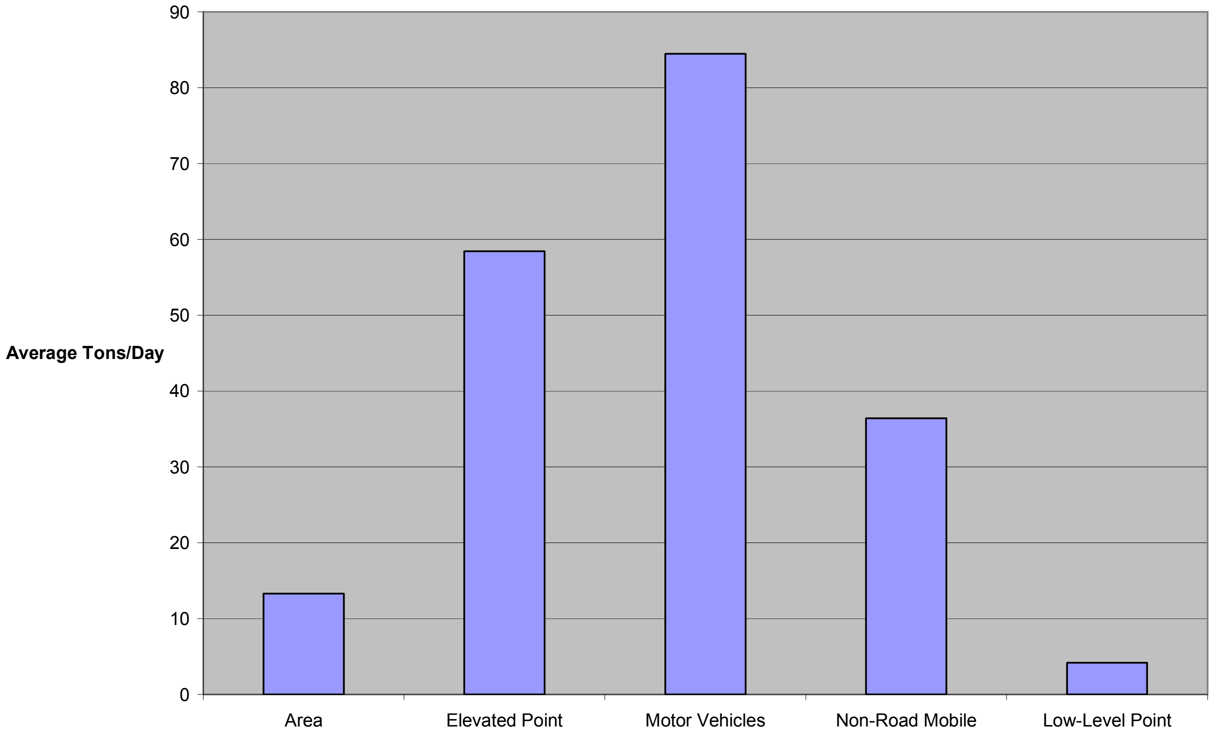


Figure 1-10b. Anderson, Greenville, Spartanburg area VOC 1998 Episode Emissions

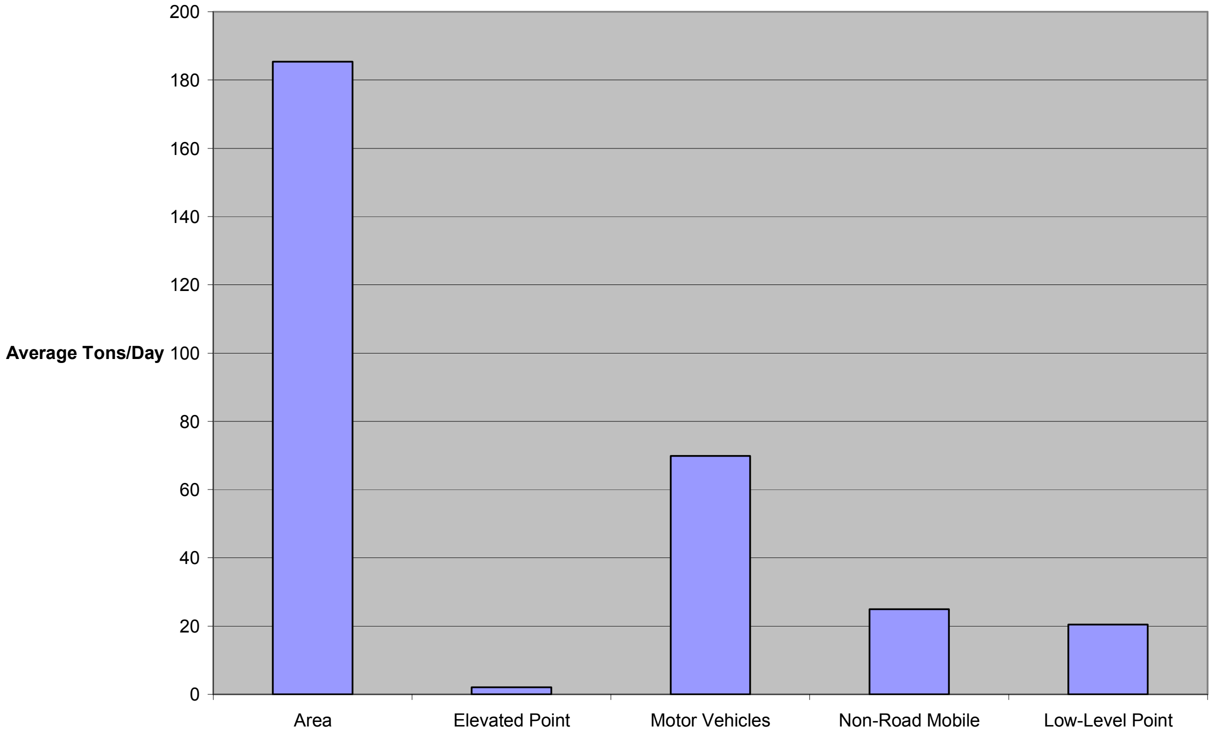


Figure 1-10c. Anderson area NOx 1998 Episode Emissions

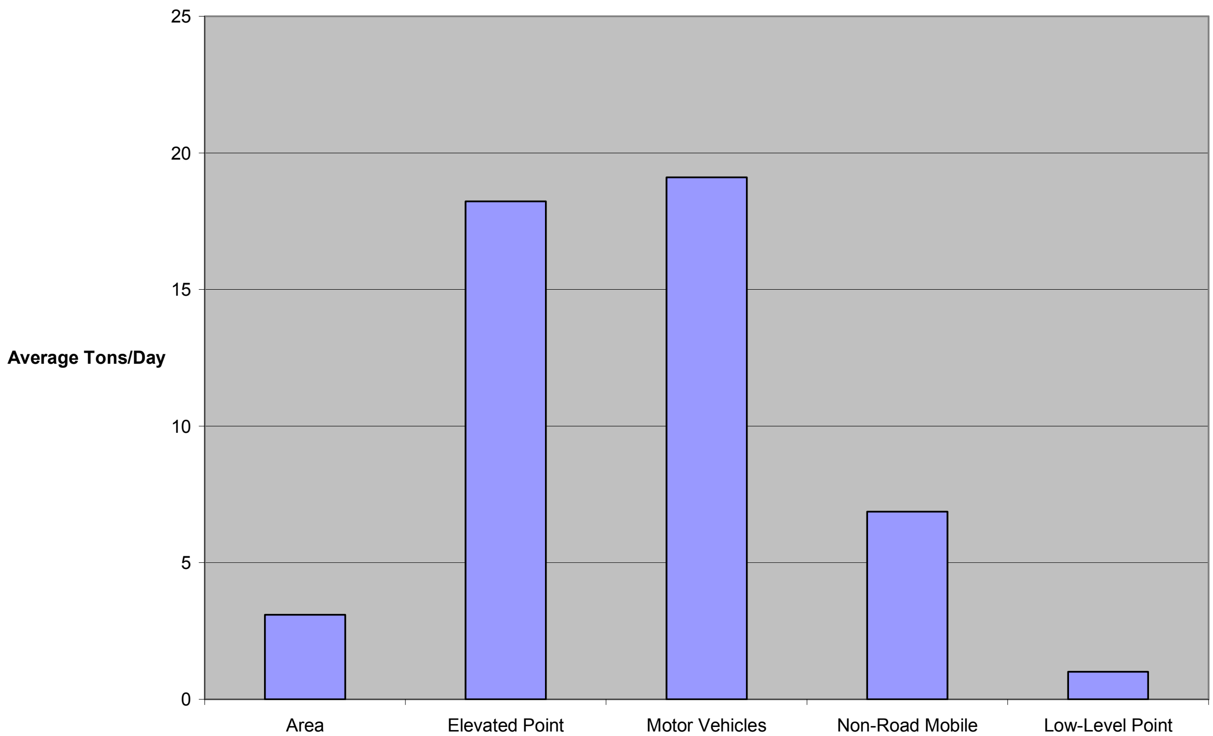


Figure 1-10d. Anderson area VOC 1998 Episode Emissions

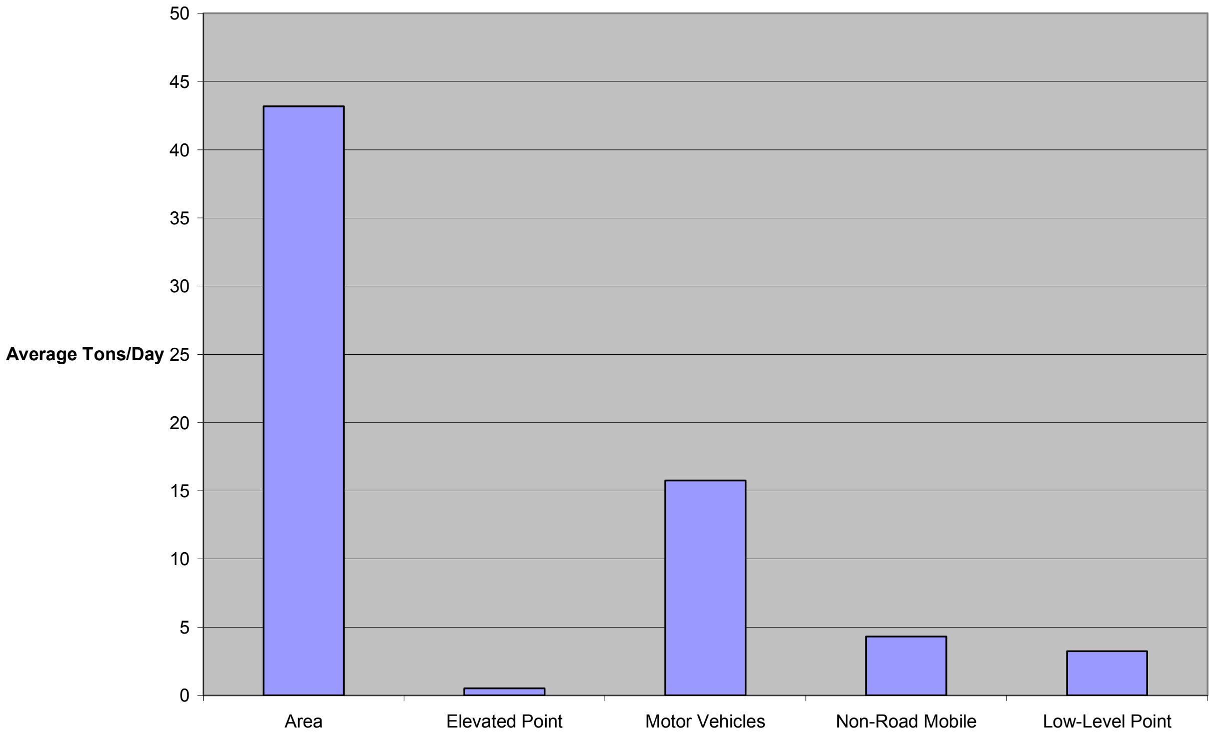


Figure 1-10e. Greenville area NOx 1998 Episode Emissions

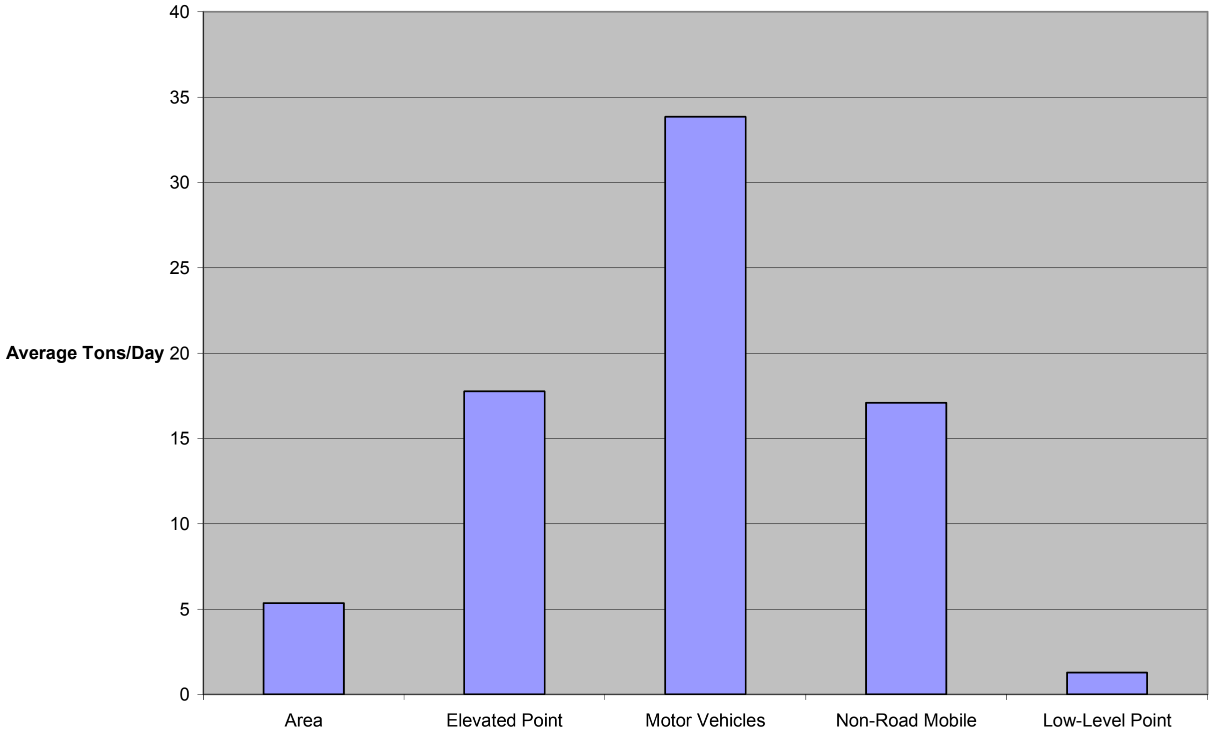


Figure 1-10f. Greenville area VOC 1998 Episode Emissions

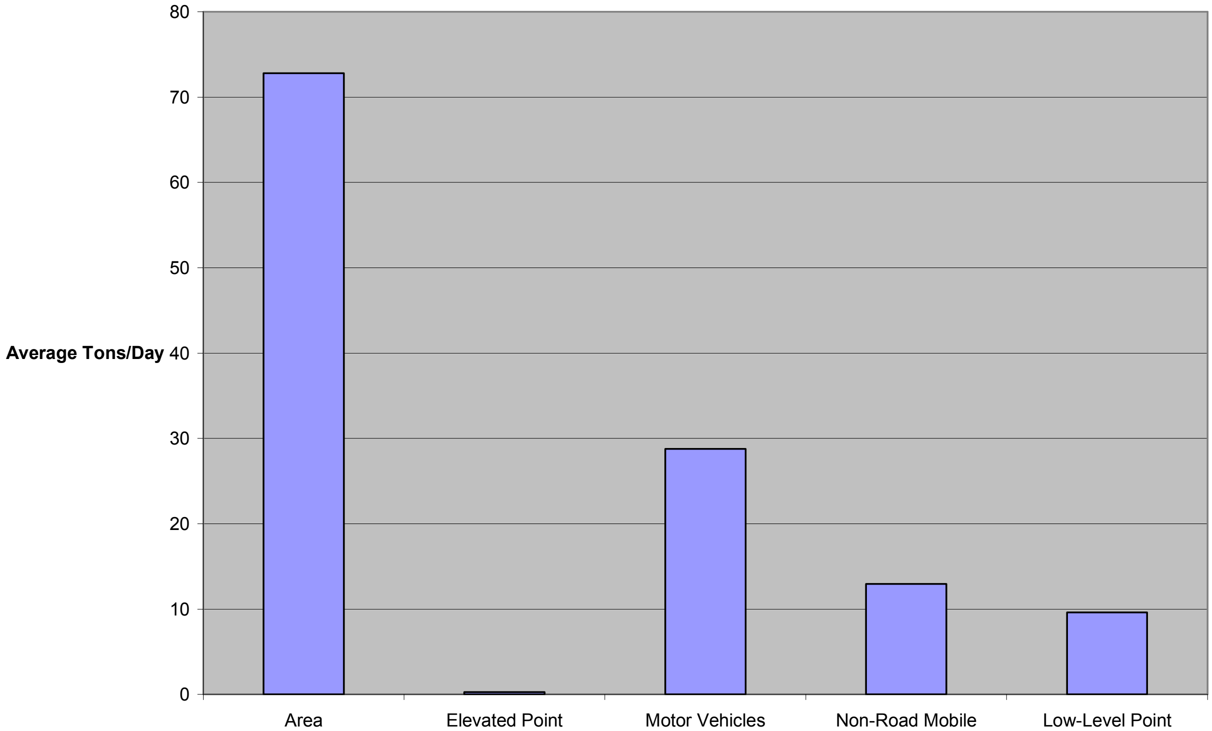


Figure 1-10g. Spartanburg area NOx 1998 Episode Emissions

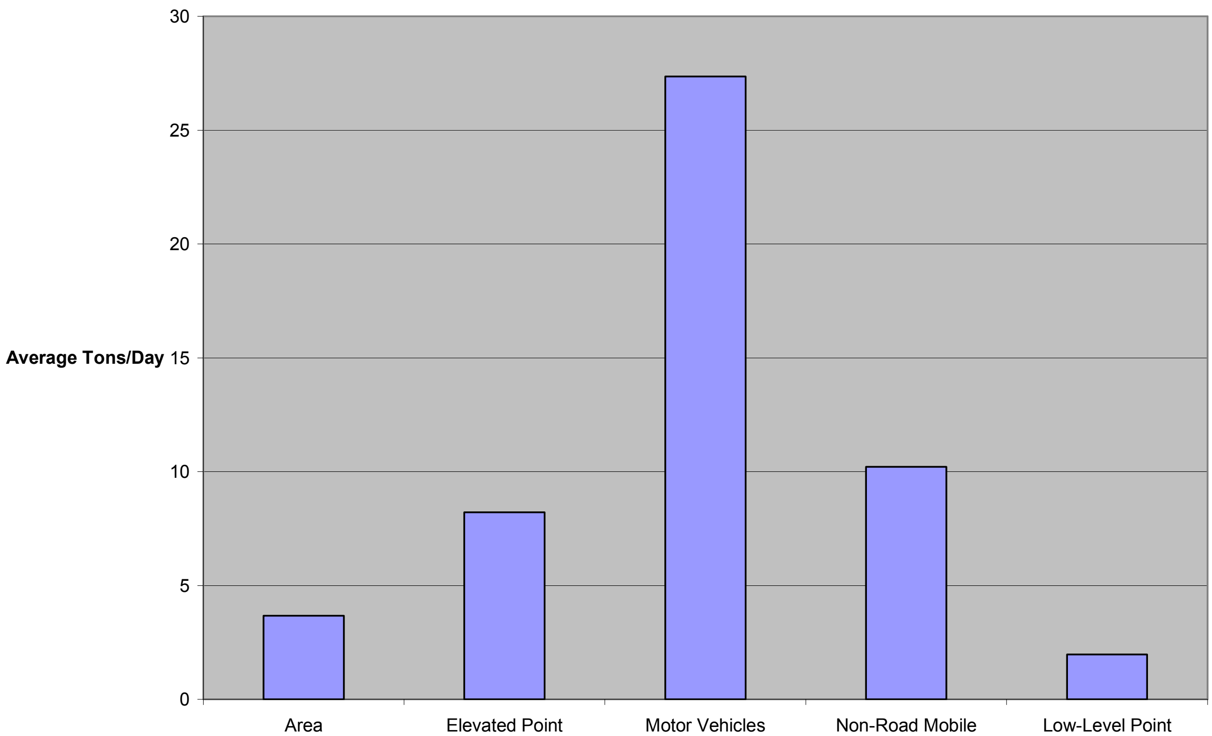


Figure 1-10h. Spartanburg area VOC 1998 Episode Emissions

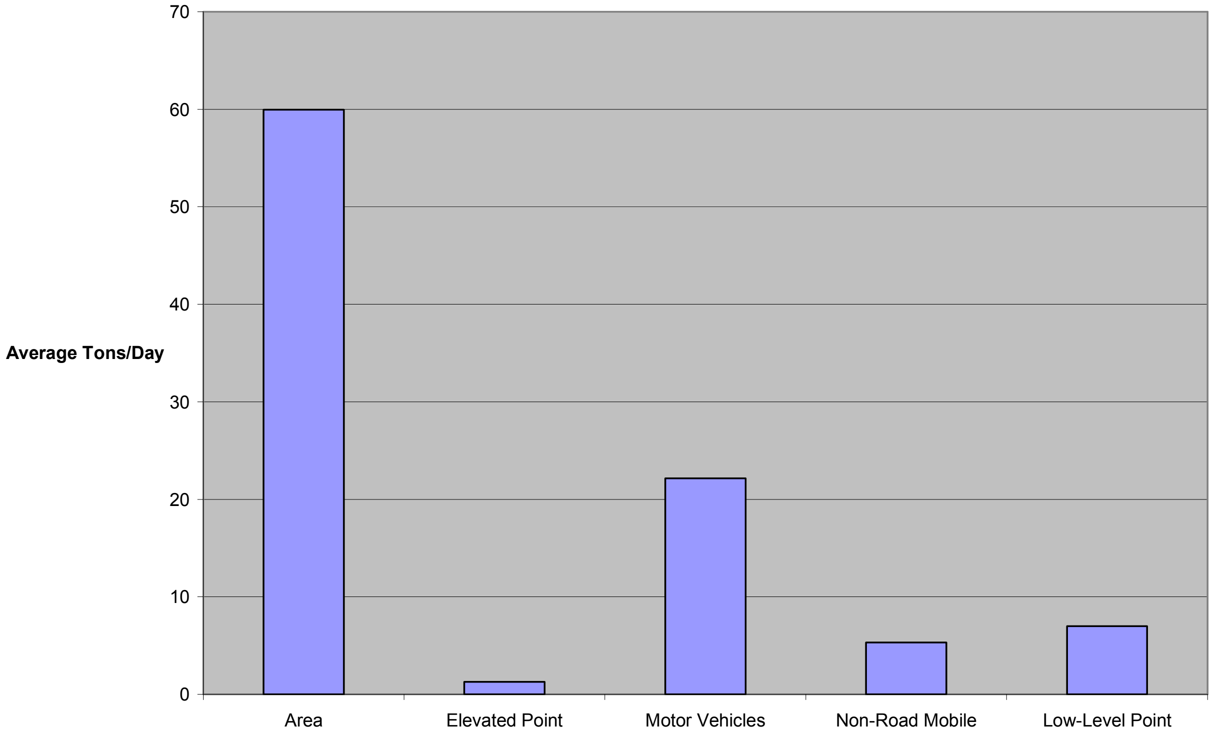


Figure 1-10i. Columbia area NOx 1998 Episode Emissions

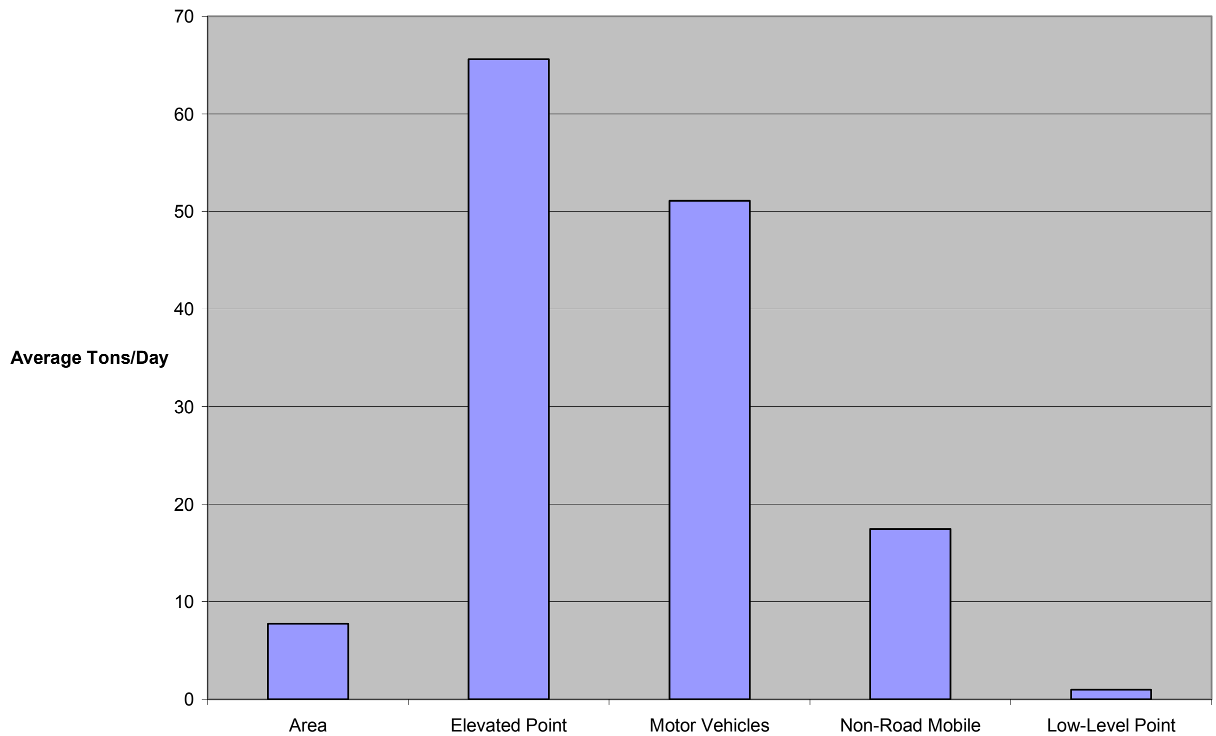
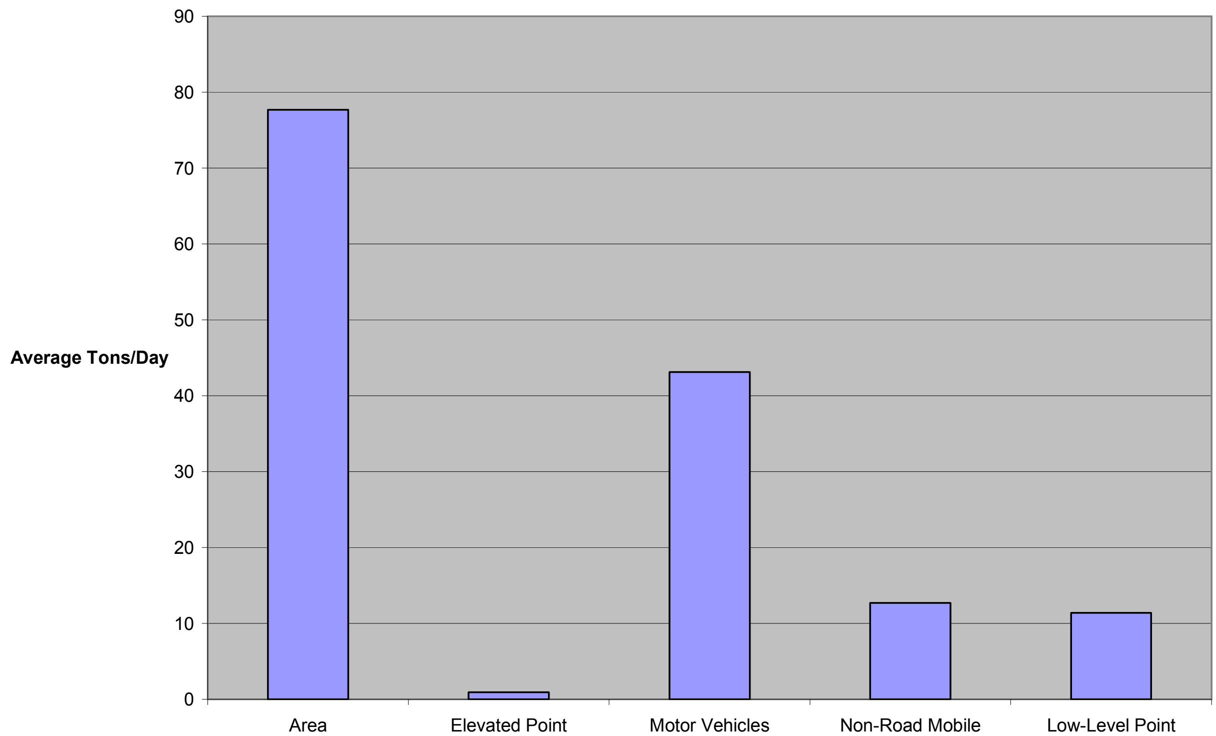


Figure 1-10j. Columbia area VOC 1998 Episode Emissions



II. Technical Protocol

The modeling protocol document for the South Carolina 8-hour ozone modeling analysis was prepared in December 2002 and updated July 2003. The protocol document provides information regarding the organizational structure of the modeling study, study participants, communication structures, and the resolution of technical difficulties. It also provides detailed information on each element of the modeling analysis, including selection of the primary modeling tools, methods and results of the episode selection analysis, modeling domain, model input preparation procedures, model performance evaluation, use of diagnostic and sensitivity analysis, future-year modeling, application of the EPA ozone attainment demonstration procedures, and documentation procedures. Archival and data acquisition procedures are also outlined in this document. The modeling protocol document is provided as a separate document to this report.

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III. Base-Case Modeling Emission Inventory Preparation

This section discusses the development of the base-year emission inventory for the May 1998 modeling episode period. A 1998 emissions inventory was developed for use as the current year emissions inventory. The emission-processing tools used in preparing the inventory are EPA's UAM Emission Preprocessor System Version 2.5 (EPS 2.5), MOBILE 6, NONROAD and BEIS-2.

For ease of reading, all figures follow the text of this section.

South Carolina has chosen to use 1998 emissions data for the most current year instead of 1999 data. There are two reasons for this choice. First, the 1998 inventory is considered more representative and conservative than the 1999 emissions inventory. Second, these inventories were created prior to EPA guidance calling for 1999 or later emissions data to be used. If these inventories were recreated using 1999 data, South Carolina would likely not be able to meet the deadlines for completion of the modeling and would face a tremendous financial cost in developing the new inventories. Substantial resources were expended to get the 1998 emission inventories to their current status. A change now would be a poor financial choice given the minimal benefit using later data would provide.

The first issue concerns the change of emissions from 1998 to 1999. Tables 3-1 and 3-2 compare these two periods of time for NO_x and VOC for South Carolina sources:

Table 3-1.
Comparison of 1998 and 1999 Inventory Years NO_x Emissions for South Carolina

Source	1998 NO_x emissions (tpd)	1999 NO_x emissions (tpd)	Difference (tpd)	Difference (%)
Point	463.3	410.3	-53.0	-11.44
Area	57.2	59.1	+1.9	+3.32
Non-road Mobile	159.7	145.7	-14.0	-8.77
On-road Mobile	344.0	~355.0[1]	+11.0	+3.2
TOTAL	1024.2	970.1	-54.1	-5.28

1- The on-road VMT increased by 2.8 % from 1998 to 1999. The number shown is an approximation based on the 3.2 % increase. SC used actual measured data from our state DOT to calculate the on-road emissions data. The data for on-road emissions in the 1999 NEI for SC was calculated by a contractor and differs (428.65 tpd) due to the method used to distribute the VMT data (actual measurements were not used). Please see below for further discussion.

Table 3-2.
Comparison of 1998 and 1999 Inventory Years VOC Emissions for South Carolina

Source	1998 VOC emissions (tpd)	1999 VOC emissions (tpd)	Difference (tpd)	Difference (%)
Point	120.0	105.38	-14.62	-12.18
Area	769.0	451.91	-317.09	-41.23
Non-road Mobile	127.77	118.66	-9.11	-7.13
On-road Mobile	282.0	276.27	-5.73	-2.03
TOTAL	1298.77	952.22	-346.55	-26.68

As shown above, the emissions of NO_x and VOC for South Carolina decrease for 1999 when compared with 1998. For VOC the reduction is 26.7%, and for NO_x the reduction is 5.3%. This means that the use of 1998 data would be more conservative for South Carolina, and the use of 1998 emissions data should satisfy EPA's current year requirements.

When comparing SC 1999 NEI version 2 emissions data to the 1998 emissions generated by SC to be used in ozone modeling, it was found that the 1999 NEI data were almost 20% higher for on-road mobile daily NO_x emissions. This seemed very high, especially compared to the little difference from the other sources of NO_x and also from CO and VOC. This issue was investigated further to see what might be causing this large difference. A sort of the on-road mobile NO_x emissions in the NEI data tables revealed that some of the smaller population counties in the state were near the top for NO_x emissions. Most of the higher NO_x emissions came from light duty gas vehicles (LDGV) on rural interstates. Further investigation indicated the method used for allocating VMT to the county and road type levels was causing the differences in NO_x emissions. The total annual statewide VMT used in the 1999 NEI and in the SC 1998 ozone modeling study are very similar, as Table 3-3 below indicates:

Table 3-3.
Comparison of 1998 SCDOT and 1999 NEI VMT Data for South Carolina

	SC 98 Modeling Study		99 NEI Final version 2	
Annual Statewide VMT	42,912,269,922.0 miles		44,145,704,316.35 miles	
Avg Ozone Season Day VMT	114,530,939.6 miles		132,470,242.9 miles	
Month of Ozone Season Analysis	May		July	
OSD Temps used in input files	Low- 65	High- 91	Low-72.1	High- 91.2

SC used 1998 annual VMT by county and road type, collected by the SC Dept. of Transportation (SCDOT). These numbers are based on actual road studies by the SCDOT. The 1999 NEI VMT starts out with SCDOT annual VMT, which is reported to the Federal Highway Administration (FHWA) who enter the data in the Highway Performance Management System (HPMS). EPA takes this annual number and allocates it temporally by county and road type, using different allocation factors. According to Laurel Driver of the USEPA-OAQPS, the contractor allocated the VMT data to rural interstates using the actual miles of rural interstate in each county. Distributing the VMT in this manner resulted in more VMT being put on rural interstates than what the actual road count data indicated in 1998. Rural interstates typically have a higher emission factor than the other road types because of the high speeds. This explains much of the difference between the two years' emissions. In summary, the 1998 on-road mobile emissions were calculated using actual 1998 VMT, and the 1999 NEI v.2 on-road mobile emissions were calculated with VMT data generated by the use of multiple allocation factors. Using actual VMT data is more representative than using VMT developed by allocation factors.

The second issue concerns both the time and money. The legislative process South Carolina uses leaves little time to complete the modeling work. In order to meet the EAC deadlines, South Carolina regulations and SIP development must take final shape by late summer 2003 so they can go through the legislative process and receive final approval by the SC DHEC Board by early January of 2004 at the absolute latest. This means the sensitivity analyses and control strategy modeling runs must be completed by late summer 2003 to ensure the chosen strategies will allow South Carolina to be in attainment with the 8-hr ozone standard by 2007. Because of the tight schedule, South Carolina developed inventories for 2007, 2012 and 2017 based on the 1998 episode emissions data before EPA released its guidance on EAC modeling. As stated earlier, if South Carolina starts over and uses 1999 emissions data, it would be very difficult to meet the deadlines required by the South Carolina legislative process. There would also be a significant additional cost associated with having to get a contractor to redo the inventory data based on 1999 data. South Carolina would have to get this work done by an outside contractor, as the capabilities to do this work in-house do not exist at this point in time since South Carolina has very limited prior experience with ozone modeling. This extra burden and substantial financial cost make little sense; especially given the emissions are higher in South Carolina in 1998 than they were in 1999.

Therefore, based on the issues raised above, South Carolina has chosen to use 1998 emissions data in lieu of 1999 data for the Early Action Compact ozone modeling.

A. Emission Data Sources

The modeling inventories for the episode were prepared based on the following information:

- 1996 National Emissions Trend (NET) Version 3 emission inventory.
- Emissions data provided by states for specific years.
- Episode-specific emissions data provided by individual facilities.

The 1996 NET inventory includes annual and ozone season daily emissions for oxides of nitrogen (NO_x), volatile organic compounds (VOC), carbon monoxide (CO), sulfur dioxide (SO_2), particulate matter with a diameter less than 10 and 2.5 microns (PM_{10} and $PM_{2.5}$), and ammonia (NH_3). Since the modeling inventories were prepared for use in ozone modeling applications, the ozone season daily emissions of NO_x, VOC, and CO from NET 96 were used for the modeling analysis.

B. Overview of Emissions Processing Procedures

To facilitate development of the detailed emission inventories required for photochemical modeling for this analysis, EPA's UAM Emission Preprocessor System, Version 2.5 (EPS 2.5) was used. This system, developed by SAI, consists of series of computer programs designed to perform the intensive data manipulation necessary to adapt a county-level annual or seasonal emission inventory for modeling use. EPS 2.5 provides the capabilities, and allows for the evaluation of proposed control measures for meeting Reasonable Further Progress (RFP) regulations and special study concerns.

The core EPS 2.5 system consists of a series of FORTRAN modules that incorporate spatial, temporal, and chemical resolution into an emission inventory used for photochemical modeling. Point, area, non-road and on-road mobile source emissions data were processed separately through the EPS 2.5 system to facilitate both data tracking for quality control and the use of data in evaluating the effects of alternative proposed control strategies on predicted future air pollutant concentrations.

Chemical Speciation

All point, area, non-road mobile, and on-road motor vehicle emissions were chemically speciated from VOC into Carbon Bond Mechanism toxic species (CB4-tox). The speciation profiles were generated based on the toxic compounds database and speciation profile file prepared for a previous study (Ligocki et al., 1992, Ligocki and Whitten, 1992).

Temporal Allocation

The temporal variation profiles (monthly, weekly, and diurnal) assigned in the EPS 2.5 default input files for the area and non-road mobile source categories were included in the modeling inventory. If peak ozone season emissions data were provided in the input inventory, no additional seasonal adjustments were applied.

For on-road motor vehicles, the default weekly and diurnal profiles provided with EPS 2.5 were used to allocate daily emission rates by hour.

The operating schedule information (month/year, days/week, hours/day, and start hour) included in the point source input data for each source was processed through an EPS 2.5 utility to generate source-specific weekly and diurnal temporal variation profiles. These profiles were used to allocate the annual emissions to the daily emissions, adjust the daily emission rates for the day of the week, and to allocate the adjusted daily emissions to the hours of the episode day.

Episode-specific hourly emission rates (e.g., the point source data provided by Southern Company) were incorporated directly into the modeling inventory.

Spatial Allocation

Point source emissions were directly assigned to grid cells based on the source location coordinates included in the input emissions data for each source.

County-level area and non-road mobile emissions were allocated to grid cells using a combination of gridded spatial allocation surrogates and link locations. The gridded spatial allocation surrogates file includes fractions by grid cell of county area, population, and land-use for each county. To prepare this file, SAI obtained gridded land-use data from the United States Geological Survey (USGS, 1990). The land-use database, which has a spatial resolution of approximately 200 by 200 meters, includes data for over 30 land-use categories. These categories were combined with the land-use categories required by EPS 2.5 (e.g., urban, rural, residential, agriculture, deciduous forest, coniferous forest, water, etc.). Population data from the Census Bureau for 2000 were gridded based on the location of the centroid of each census block, and included in the spatial allocation surrogate file.

County-level on-road mobile emissions were allocated to grid cells using gridded roadway type and population. This file was prepared based on the Tiger/Line database (U.S. Census Bureau, 1993, 1994). The link data for limited-access primary roads, primary roads without limited access, and secondary roads were extracted from the database, and used to generate the gridded roadway type surrogate file. The airport location data from the database were used to spatially allocate the emissions from aircraft.

C. Preparation of the Area and Non-road Emission Inventory Component

Area source emissions for the states included in the modeling domain were generated based on the 1996 NET Version 3 emission inventory, with three exceptions. Data for the following areas were provided by their respective states, and supplemented by 1996 NET Version 3 data for source categories not available in state data:

- 1998 county-level emissions for South Carolina.
- 1996 county-level emissions for Mississippi.
- 1999 county-level emissions for Hamilton and Davidson, Tennessee.

County-level emission estimates for the majority of non-road mobile source emissions were developed using EPA's draft NONROAD model (June 2000 version) with the May maximum, minimum and average temperatures by state (provided by EPA's "National Air Pollutant Emission Trends, Procedures Document for 1990-1996"). Aircraft, commercial marine vessels, and locomotives were not included in the NONROAD model, and the emissions for those categories were taken from the 1996 NET database. The 1999 county-level aircraft emissions provided by SC DHEC were also incorporated in the inventory.

D. Preparation of the Mobile Source Emission Inventory Component

The on-road mobile source emissions were prepared using MOBILE6 and county-level daily vehicle miles traveled (VMT) data for the States of South Carolina, North Carolina, Georgia and Tennessee. The 1996 NET Version 3 on-road mobile emissions were used for the other states within the modeling domain.

The following data were provided by the states for on-road mobile emission inventory preparation:

State of South Carolina	MOBILE6 input for 1998 1998 county-level daily vehicle miles traveled (VMT) data.
State of North Carolina	1998 county-level daily VMT data.
State of Georgia	MOBILE6 input for 1999 (converted to MOBILE6 input for 1998) 1999 county-level daily VMT data.
State of Tennessee	MOBILE6 input for 1999 (converted to MOBILE6 input for 1998) 1998 county-level daily VMT data.

The MOBILE6 input files were used to generate the emission factors for total organic gasses (TOG), NO_x, and CO. The county-level emissions were calculated for each vehicle class and roadway classification by multiplying the appropriate emission factor from MOBILE6 by the county-level VMT for that vehicle class and roadway classification, using the EPS 2.5 program MVCALC.

For the other states, the on-road mobile source emissions were generated based on the 1996 NET Version 3 data. The growth and adjustment factors developed by Department of Civil and Environmental Engineering, University of Tennessee were applied to the NET 96 data to project emissions from the 1996 MOBILE 5b level to the 1998 MOBILE 6 level.

E. Preparation of Point Source Emission Inventory Component

The point source emission inventory was prepared based on emissions provided by States of Alabama, Mississippi, South Carolina, North Carolina, and Tennessee. Emissions for the other states were based on the NET 96 Version 3 data base.

Southern Company and the utilities in South and North Carolina provided episode-specific point source emissions.

The detailed state- and facility-specific point source data are as follows:

State of South Carolina	Episode-specific emissions for Duke Lee and CP&L Robinson based on US EPA Clean Air Markets 1998 Acid Rain data base; Episode-specific emissions for Santee Cooper and SCE&G facilities; 1998 annual emission data for other facilities.
State of North Carolina	Episode-specific emissions for utilities based on US EPA Clean Air Markets 1998 Acid Rain data base.
State of Alabama	1999 annual point source emissions.
State of Mississippi	1999 annual point source emissions.
State of Tennessee	1999 annual point source emissions for Hamilton, Knox, Davidson, and Shelby County, Tennessee.

The point source data provided by Southern Company and utilities in South and North Carolina include hourly emission rates, which were used to calculate daily emissions and to create the episode-specific diurnal profiles for each source, for each episode day. In addition to providing the location, stack height, and exit diameter, the point source data provided by Southern Company include hourly flow rate and exit temperature for each source, and this information was also incorporated in the modeling inventory.

F. Estimation of Biogenic Emissions

The EPA's Biogenic Emission Inventory System (BEIS-2) was used to estimate day-specific biogenic emissions for the modeling analysis with Version 3.1 of the Biogenic Emissions Landcover Database (BELD3). Gridded surrogates of land use/vegetation information were created at 4-km resolution for the entire modeling domain, based on the 1-km BELD3 data. Biogenic emissions were then calculated using the 4-km resolution information. Temperature and solar radiation estimates were extracted from the output of the MM5 meteorological model.

G. Quality Assurance

Quality assurance involved tracking the emission inventory data sets through each step of modeling inventory preparation. The summary message files produced by each EPS 2.5 module were reviewed to identify any warning or error messages indicating potential problems in processing, and to verify input and output emission totals for each processing step.

Graphic representations of the spatial variation in each component (area source emissions, biogenic emissions, etc.) of the final UAM-V ready modeling inventory files were prepared and reviewed for appropriateness.

After each of the inventory components were completed and merged, the emissions were summarized by major inventory component for all grids in the modeling domain, for each of the episode days. The final review was performed before the UAM-V modeling.

H. Summary of the Modeling Emissions Inventories

The emission summaries for the 1998 base case episode are presented in Tables 3-4 through 3-6. The emission summaries are given by species (NO_x, VOC and CO) and by major source category. The low-level emissions include anthropogenic (area, non-road, on-road motor vehicle, and low-level point sources) and biogenic sources. The units are in tons per day.

Graphical depictions of the emissions are provided for the South Carolina, Georgia and North Carolina domain (Grid 3) in Figures 3-1 to 3-7, following the tables. Biogenic VOC emission estimates derived using the BEIS-2 algorithm differ by episode day due to different ambient temperatures. Figure 3-1 presents emission density plots of biogenic VOC emissions for 18 May 1998 as one representative day of the episode.

Anthropogenic emissions do not vary day-to-day as much as biogenic emissions. Figures 3-2 through 3-7 provide NO_x and VOC emission density plots for area source, mobile sources, and total low-level anthropogenic emissions, respectively, for 18 May 1998, illustrating emissions for a typical weekday of the episode. Figures 3-8 and 3-9 present NO_x and VOC emissions, respectively, for elevated point sources for 18 May 1998. (Note: the largest circle in Figure 3-9 reflects an error in emissions for one facility in Alabama. This error has been corrected in the emissions inventory used in the modeling.) The locations of the circles depict the location of the sources while the size of the circles represents the magnitude of the emissions. Figure 3-10 presents average daily (18 – 22 May) NO_x and VOC emissions from area sources, elevated and low-level point sources, and on-road and off-road mobile sources for the early action compact areas that have been designated non-attainment for ozone.

Table 3-4
Summary of May 1998 SCDHEC Base Case Emissions (tons/day) in Grid 1

NOX	980516	980517	980518	980519	980520	980521	980522	980523
Area	1078	164	1115	1115	1115	1115	1115	1078
Motor vehicle	6836	5982	7192	7335	7264	7406	7905	6836
Non-road	2685	2685	3555	3555	3555	3555	3555	2685
Low-level point	295	291	316	316	316	316	316	295
Biogenic	943	927	919	968	971	991	877	859
All low-level	11837	10048	13097	13288	13220	13383	13767	11753
Elevated point	8303	8159	8497	8521	8545	8590	8529	8204
TOTAL	**20139**	**18207**	**21595**	**21809**	**21765**	**21972**	**22296**	**19957**

VOC	980516	980517	980518	980519	980520	980521	980522	980523
Area	4236	3213	7136	7136	7136	7136	7136	4236
Motor vehicle	4043	3537	4253	4337	4295	4379	4674	4043
Non-road	1957	1957	1855	1855	1855	1855	1855	1957
Low-level point	878	797	1449	1449	1449	1449	1449	878
Biogenic	73762	73669	76814	85866	77747	81801	50713	44857
All low-level	84875	83173	91506	100642	92481	96620	65826	55971
Elevated point	685	658	780	779	781	773	765	664
TOTAL	**85560**	**83831**	**92286**	**101421**	**93263**	**97393**	**66591**	**56635**

CO	980516	980517	980518	980519	980520	980521	980522	980523
Area	4770	3848	5524	5524	5524	5524	5524	4770
Motor vehicle	43314	37900	45570	46472	46021	46924	50082	43314
Non-road	14332	14332	15446	15446	15446	15446	15446	14332
Low-level point	617	609	632	632	632	632	632	617
Biogenic	0	0	0	0	0	0	0	0
All low-level	63033	56690	67171	68074	67622	68525	71683	63033
Elevated point	4289	4254	4398	4398	4399	4398	4398	4289
TOTAL	**67322**	**60944**	**71570**	**72472**	**72022**	**72923**	**76081**	**67322**

Table 3-5
Summary of May 1998 SCDHEC Base Case Emissions (tons/day) in Grid 2

NOX	980516	980517	980518	980519	980520	980521	980522	980523
Area	391	86	416	416	416	416	416	391
Motor vehicle	3375	2953	3551	3622	3586	3657	3903	3375
Non-road	941	941	1382	1382	1382	1382	1382	941
Low-level point	122	119	133	133	133	133	133	122
Biogenic	395	387	376	386	401	414	377	366
All low-level	5225	4486	5858	5939	5919	6002	6211	5196
Elevated point	3273	3194	3344	3360	3383	3427	3362	3177
TOTAL	**8498**	**7681**	**9202**	**9299**	**9302**	**9429**	**9574**	**8373**

VOC	980516	980517	980518	980519	980520	980521	980522	980523
Area	2354	1729	4061	4061	4061	4061	4061	2354
Motor vehicle	2156	1886	2268	2313	2290	2335	2493	2156
Non-road	913	913	930	930	930	930	930	913
Low-level point	456	409	862	862	862	862	862	456
Biogenic	42318	37763	39449	43844	41895	46268	33792	28148
All low-level	48196	42701	47571	52011	50039	54457	42138	34026
Elevated point	231	226	284	284	286	283	282	235
TOTAL	**48427**	**42927**	**47854**	**52294**	**50325**	**54740**	**42419**	**34261**

CO	980516	980517	980518	980519	980520	980521	980522	980523
Area	2996	2478	3461	3461	3461	3461	3461	2996
Motor vehicle	22801	19951	23989	24464	24226	24701	26364	22801
Non-road	7028	7028	7843	7843	7843	7843	7843	7028
Low-level point	372	366	381	381	381	381	381	372
Biogenic	0	0	0	0	0	0	0	0
All low-level	33197	29823	35674	36149	35911	36386	38049	33197
Elevated point	1038	1029	1051	1051	1051	1050	1050	1038
TOTAL	**34235**	**30852**	**36725**	**37200**	**36962**	**37436**	**39099**	**34235**

Table 3-6
Summary of May 1998 SCDHEC Base Case Emissions (tons/day) in Grid 3

NOX	980516	980517	980518	980519	980520	980521	980522	980523
Area	154	44	166	166	166	166	166	154
Motor vehicle	1608	1407	1692	1725	1708	1742	1859	1608
Non-road	451	451	702	702	702	702	702	451
Low-level point	34	33	38	38	38	38	38	34
Biogenic	176	174	169	170	177	189	170	164
All low-level	2424	2109	2765	2800	2791	2836	2934	2412
Elevated point	1282	1279	1397	1412	1452	1537	1493	1376
TOTAL	**3705**	**3388**	**4163**	**4212**	**4243**	**4373**	**4427**	**3788**

VOC	980516	980517	980518	980519	980520	980521	980522	980523
Area	1287	944	2231	2231	2231	2231	2231	1287
Motor vehicle	1110	971	1167	1191	1179	1202	1283	1110
Non-road	416	416	487	487	487	487	487	416
Low-level point	159	137	388	388	388	388	388	159
Biogenic	21777	18505	19885	21567	18982	24258	17438	13491
All low-level	24748	20973	24159	25863	23267	28566	21827	16462
Elevated point	102	100	139	139	141	142	143	108
TOTAL	**24850**	**21074**	**24298**	**26003**	**23408**	**28708**	**21970**	**16571**

CO	980516	980517	980518	980519	980520	980521	980522	980523
Area	1596	1336	1838	1838	1838	1838	1838	1596
Motor vehicle	11615	10163	12220	12462	12341	12583	13430	11615
Non-road	3725	3725	4472	4472	4472	4472	4472	3725
Low-level point	39	38	43	43	43	43	43	39
Biogenic	0	0	0	0	0	0	0	0
All low-level	16976	15263	18573	18815	18694	18936	19783	16976
Elevated point	412	408	439	438	439	438	438	413
TOTAL	**17388**	**15671**	**19012**	**19254**	**19133**	**19375**	**20222**	**17388**

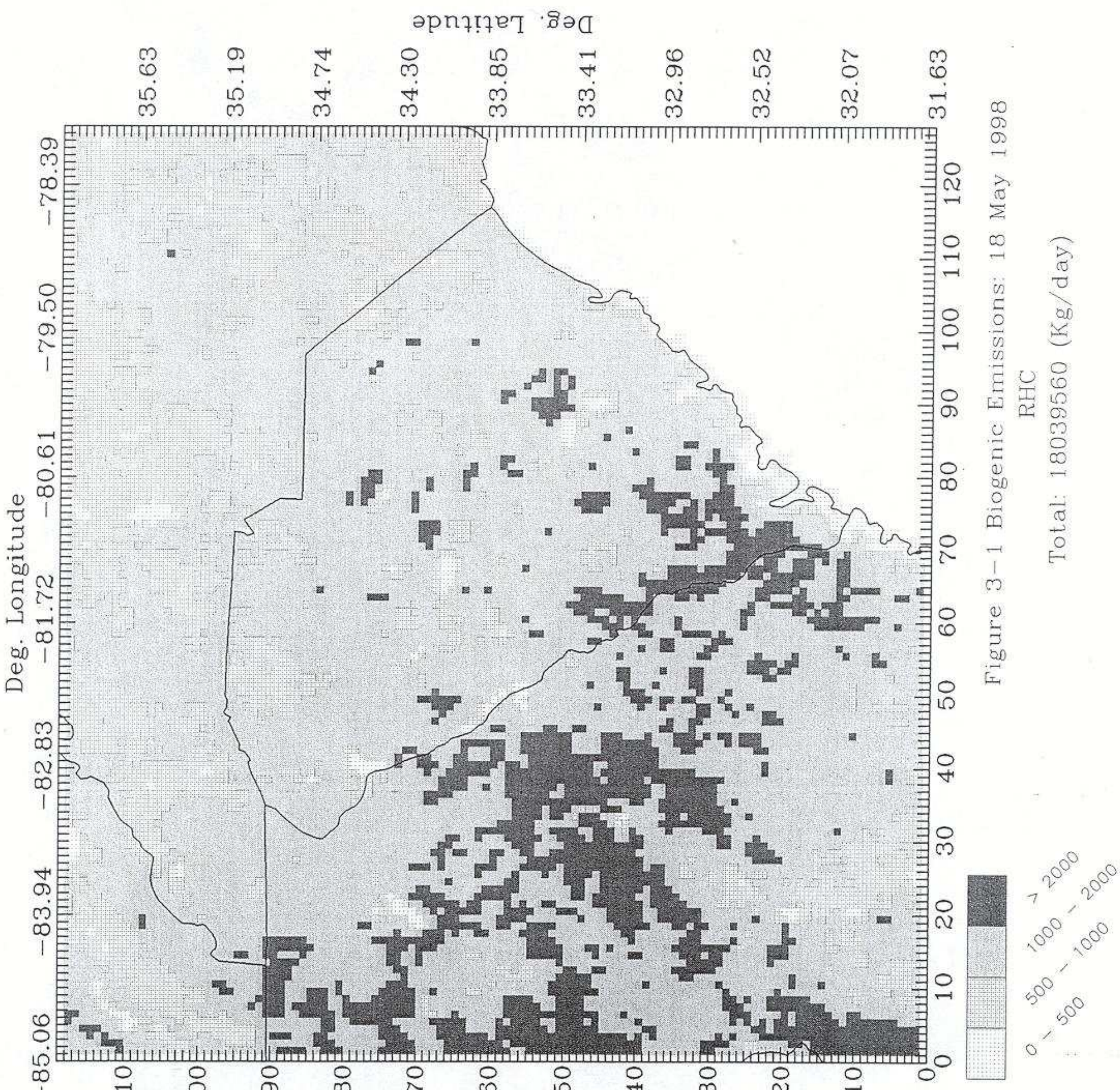


Figure 3-1 Biogenic Emissions: 18 May 1998
RHC
Total: 18039560 (Kg/day)

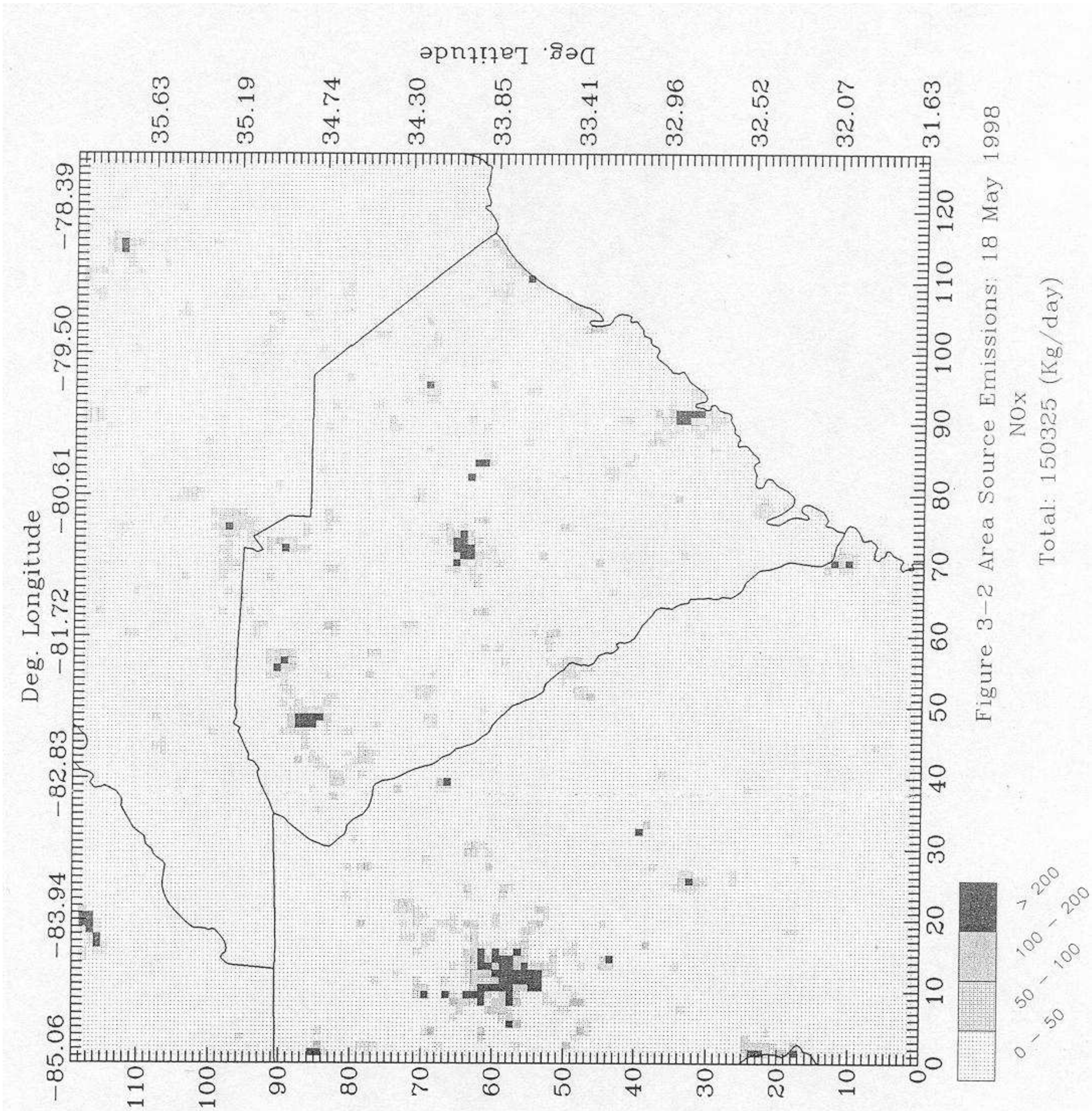


Figure 3-2 Area Source Emissions: 18 May 1998
NOx
Total: 150325 (Kg/day)

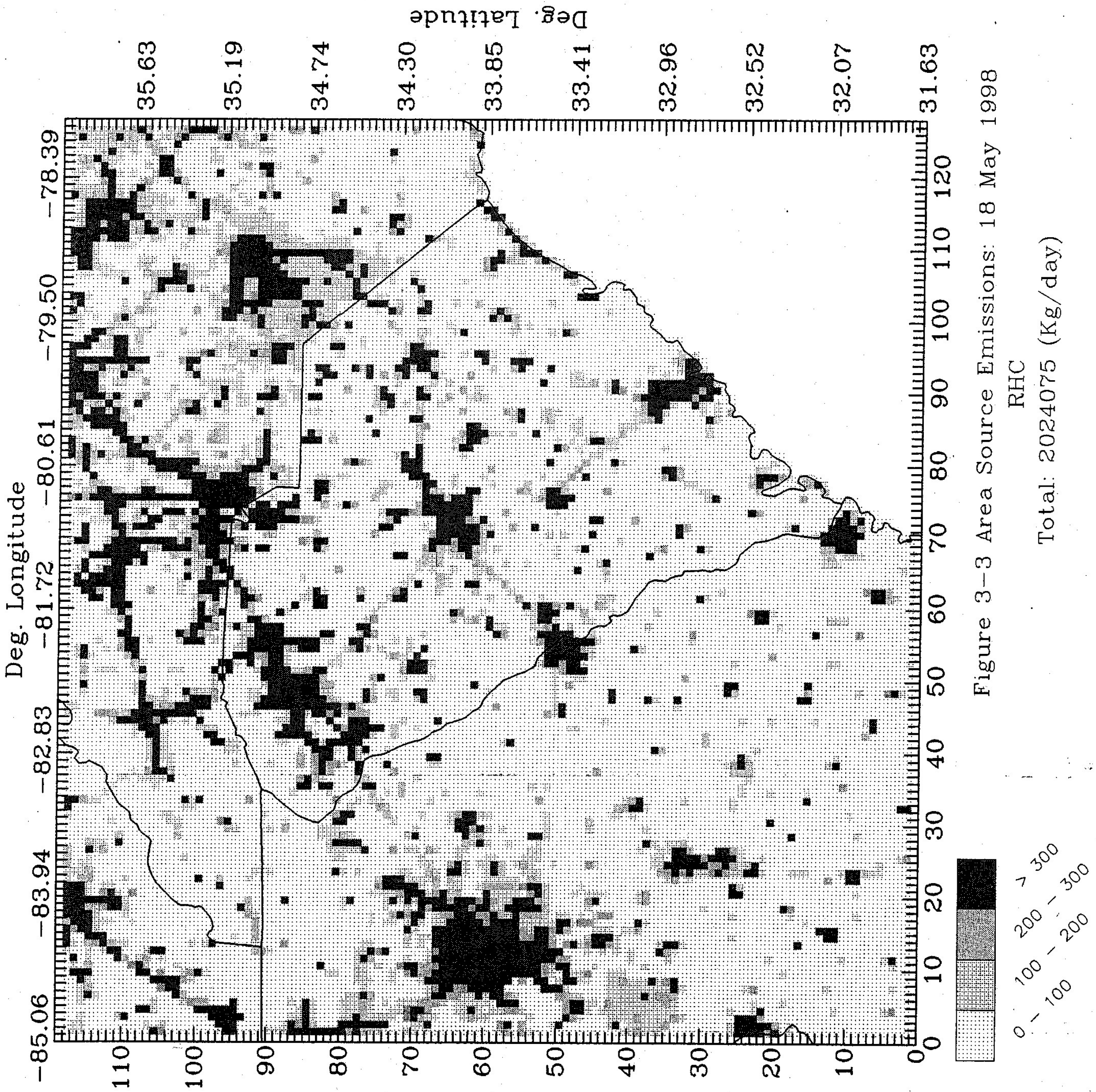


Figure 3-3 Area Source Emissions: 18 May 1998
RHC
Total: 2024075 (Kg/day)

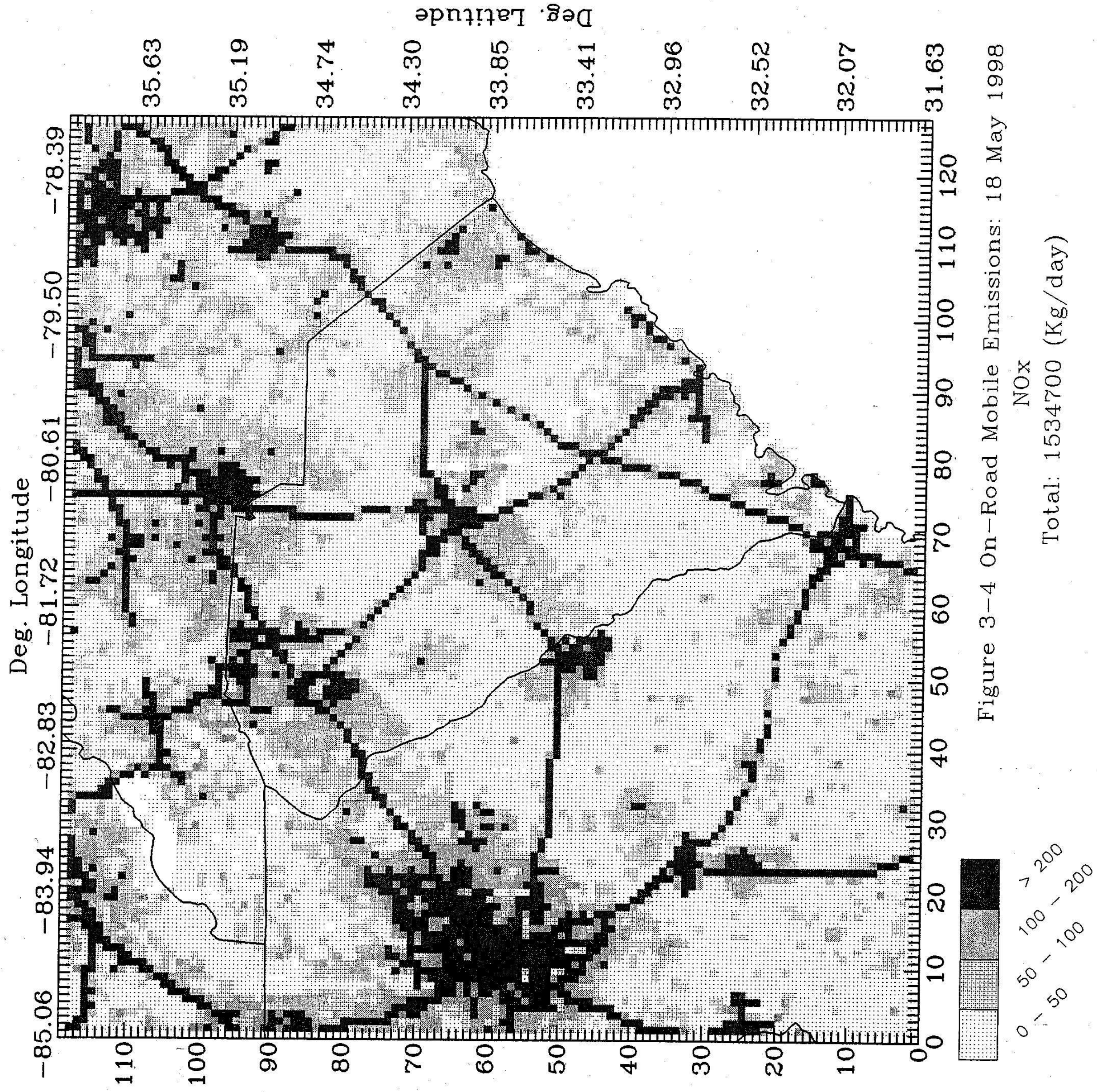


Figure 3-4 On-Road Mobile Emissions: 18 May 1998
NOx
Total: 1534700 (Kg/day)

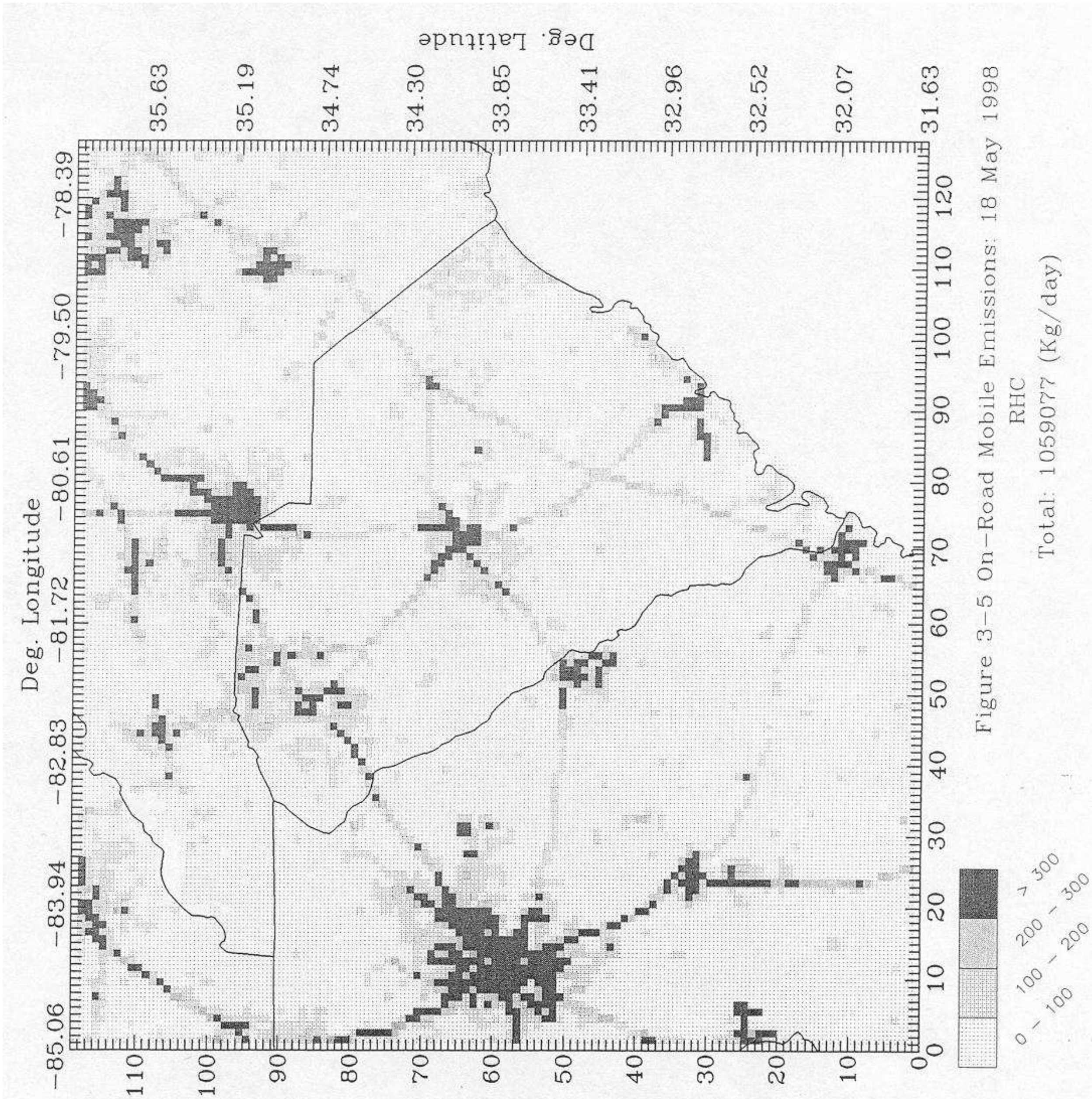


Figure 3-5 On-Road Mobile Emissions: 18 May 1998
RHC
Total: 1059077 (Kg/day)

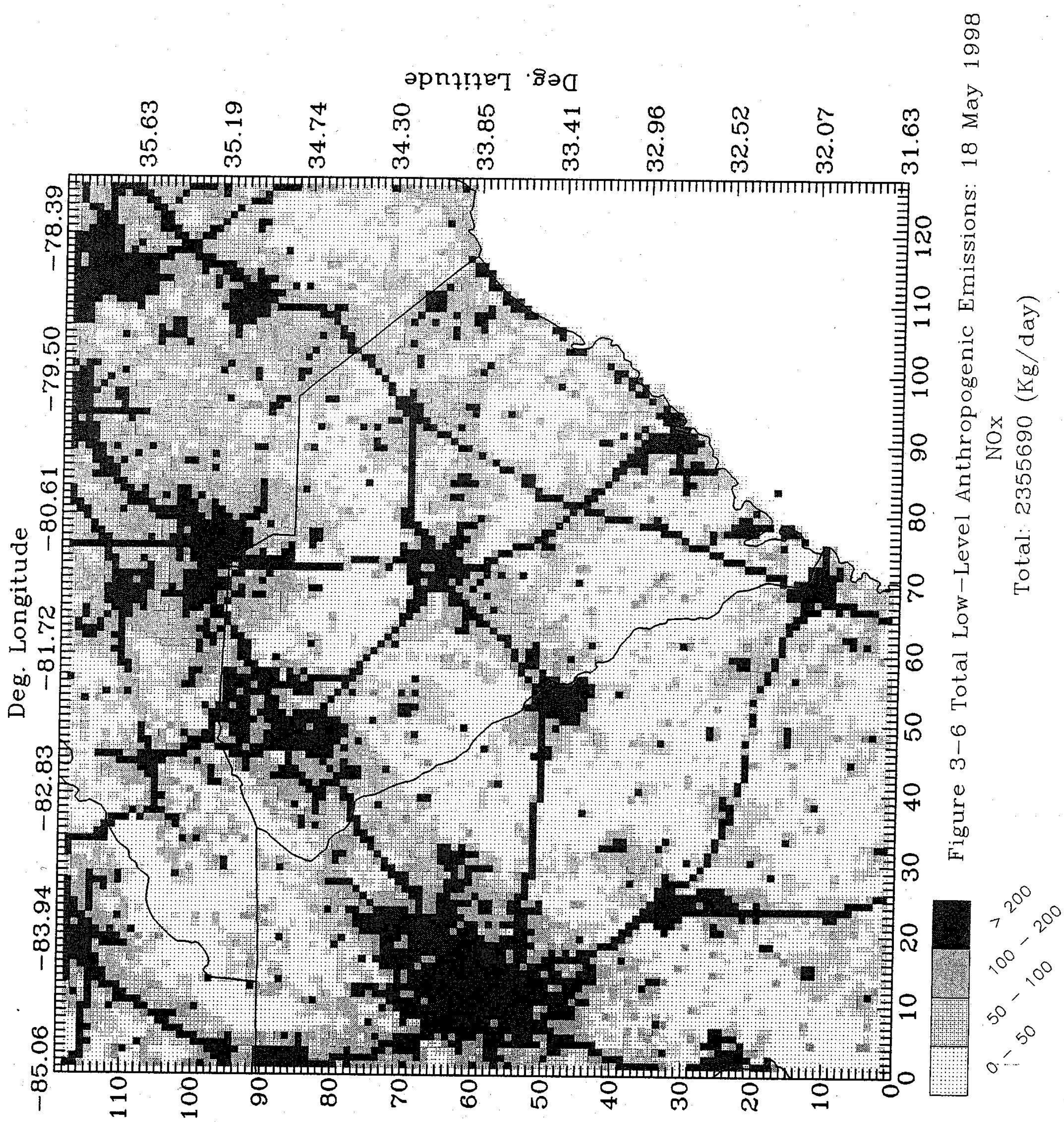


Figure 3-6 Total Low-Level Anthropogenic Emissions: 18 May 1998
NOx
Total: 2355690 (Kg/day)

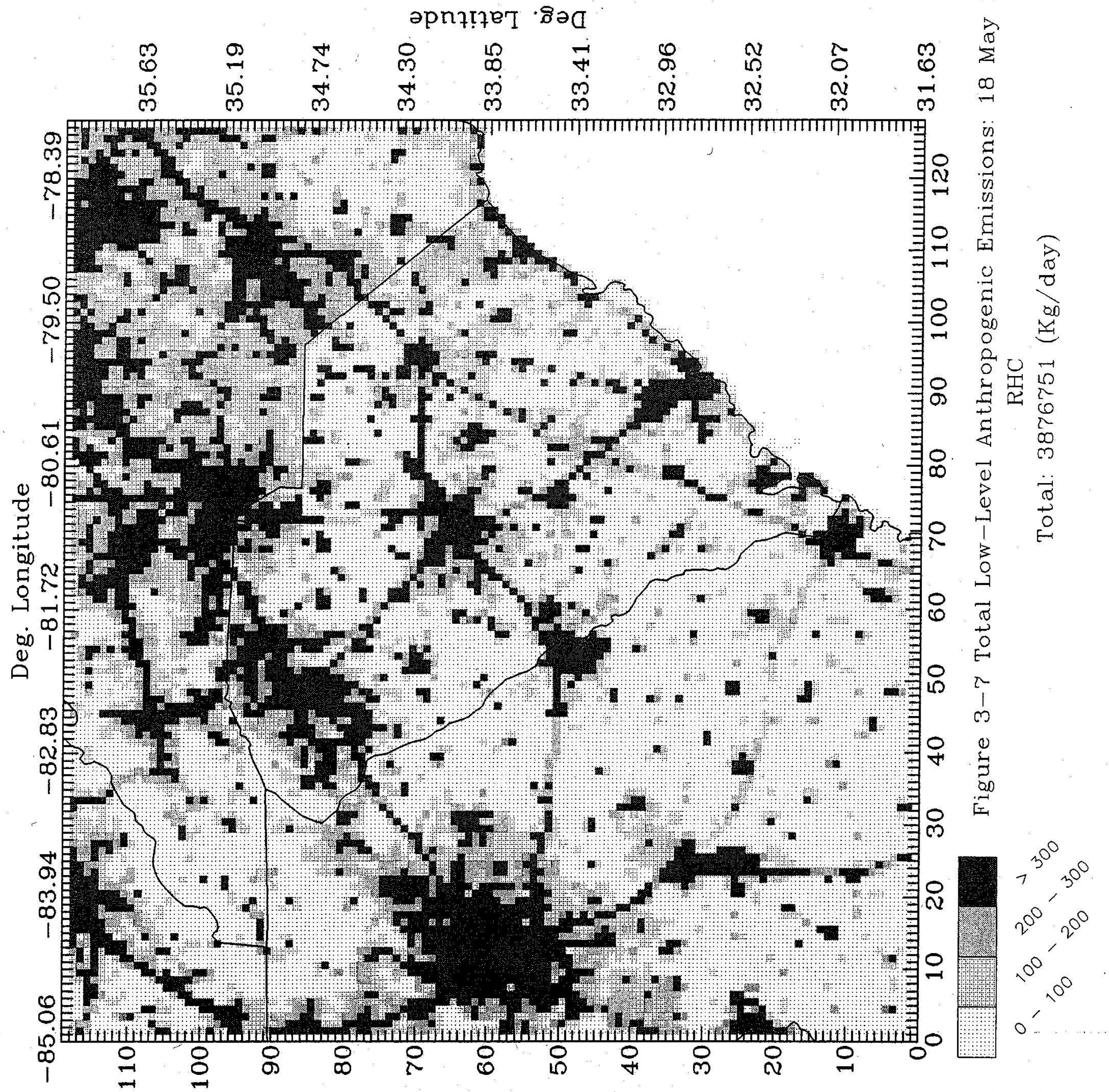


Figure 3-7 Total Low-Level Anthropogenic Emissions: 18 May 1998
RHC
Total: 3876751 (Kg/day)

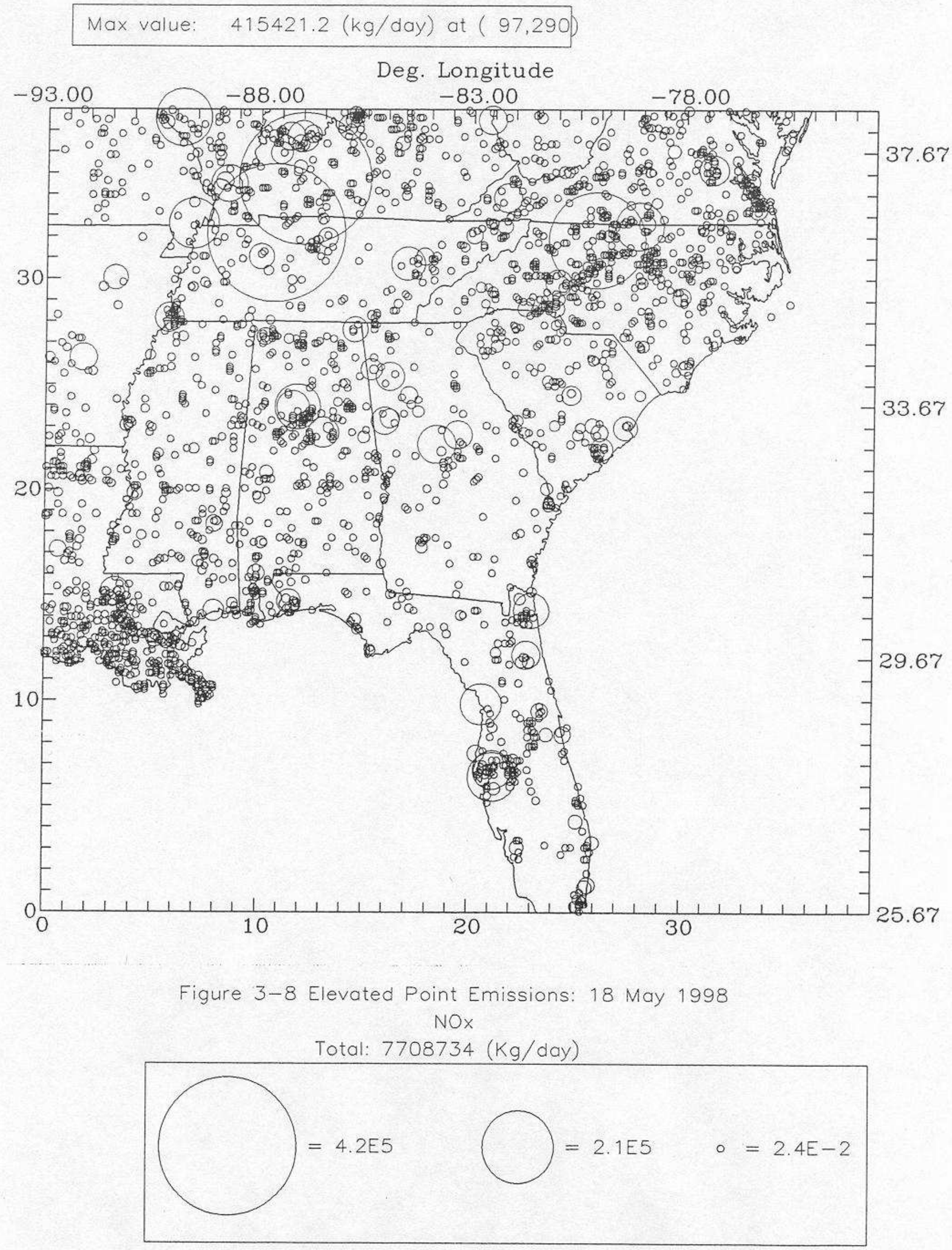


Figure 3-8 Elevated Point Emissions: 18 May 1998
NOx
Total: 7708734 (Kg/day)

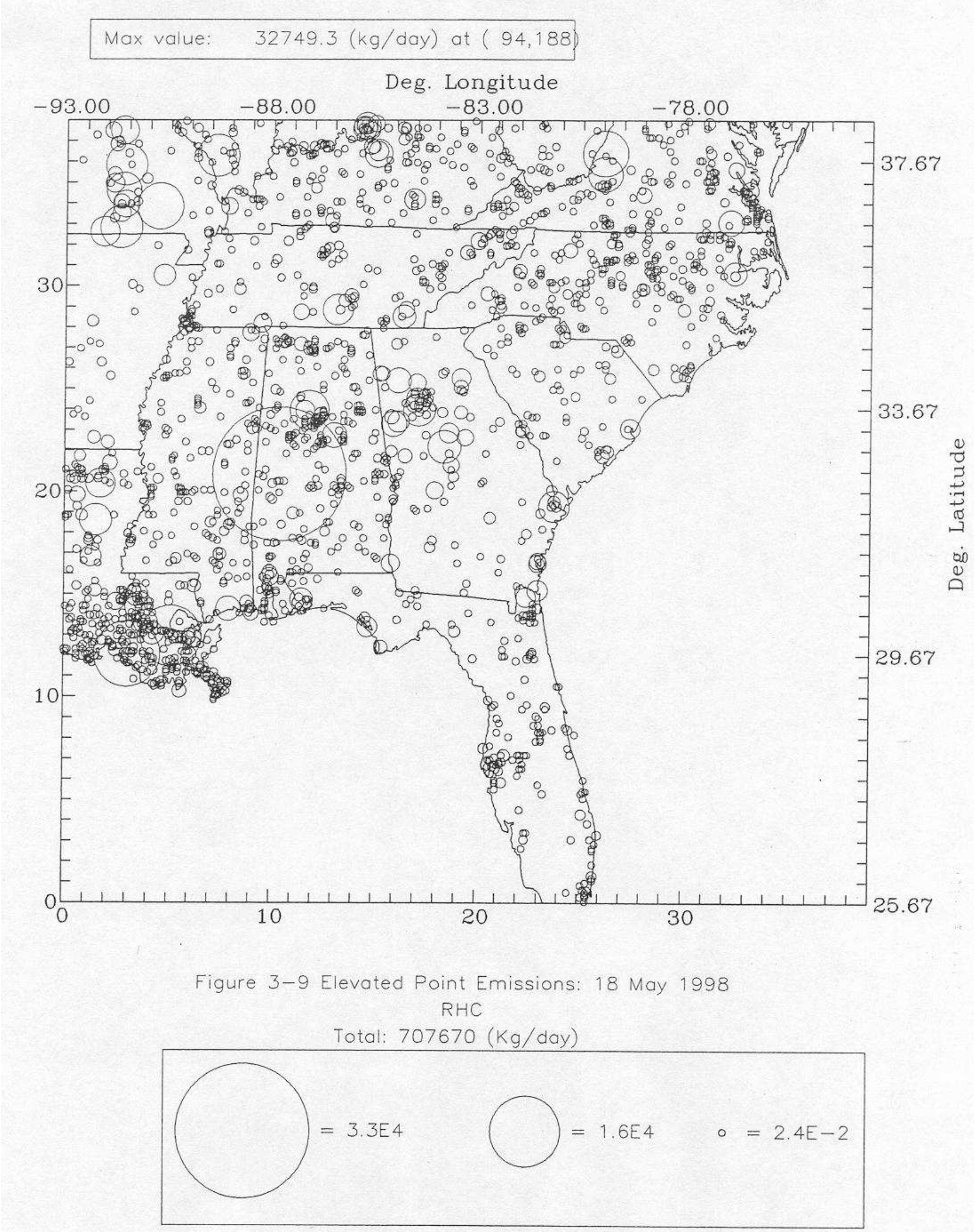


Figure 3-9 Elevated Point Emissions: 18 May 1998
RHC
Total: 707670 (Kg/day)

Figure 3-10a. Anderson, Greenville, Spartanburg area NOx 1998 Episode Emissions

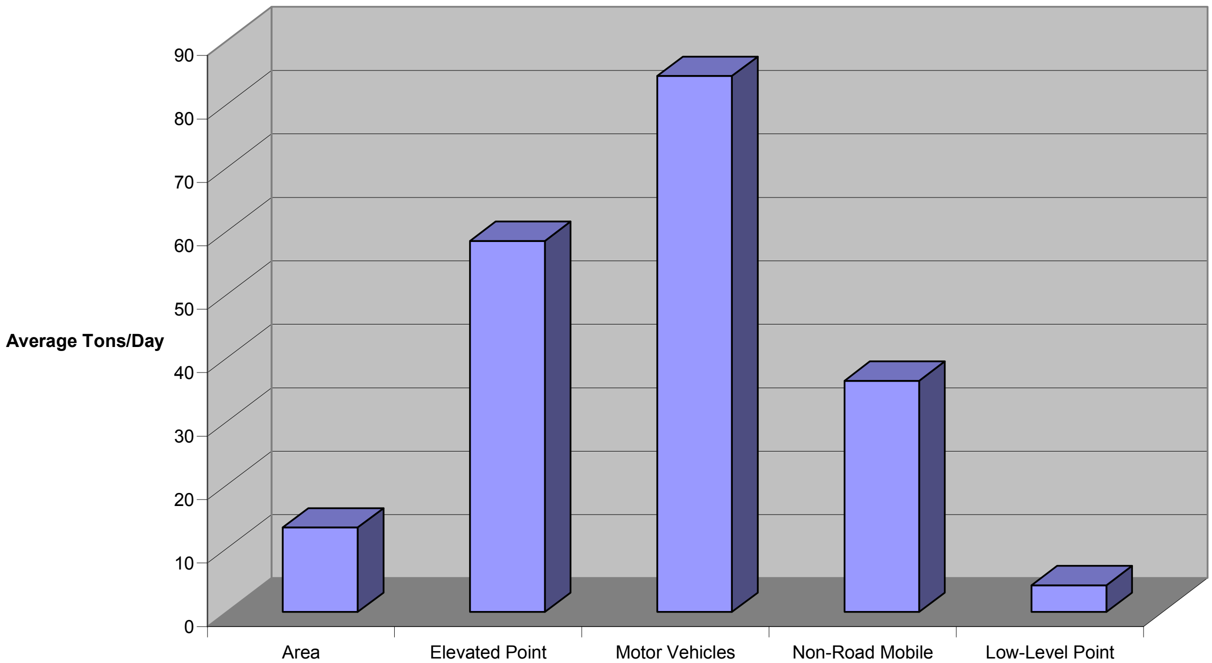


Figure 3-10b. Anderson, Greenville, Spartanburg area VOC 1998 Episode Emissions

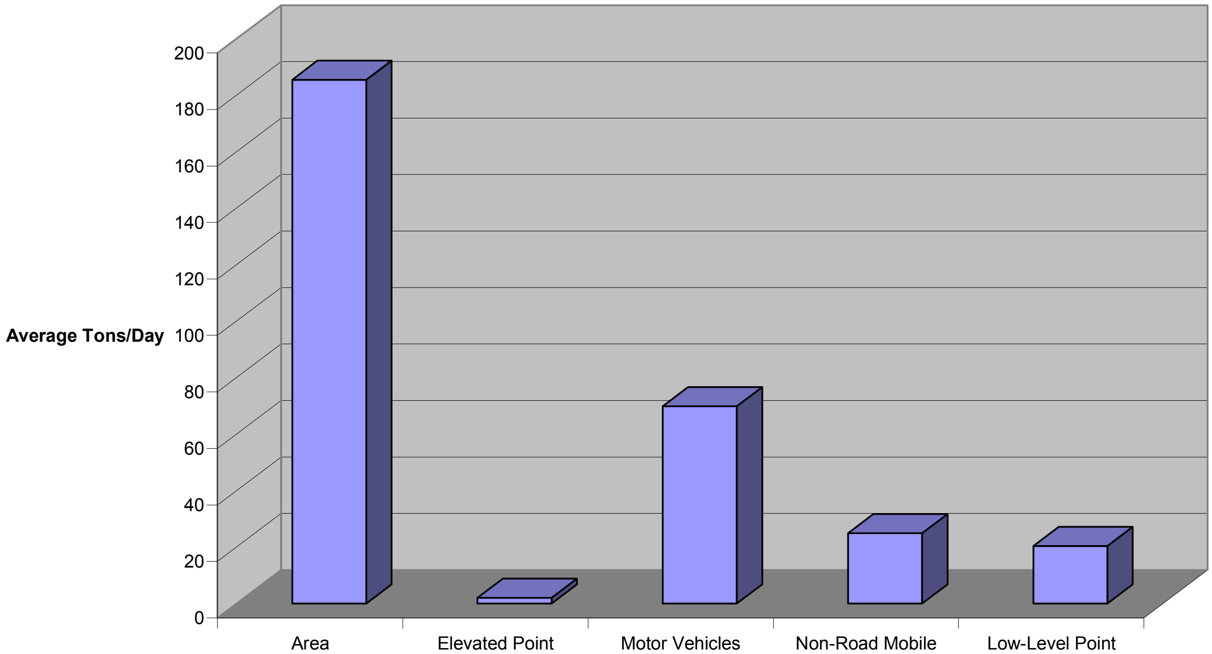


Figure 3-10c. Anderson area NOx 1998 Episode Emissions

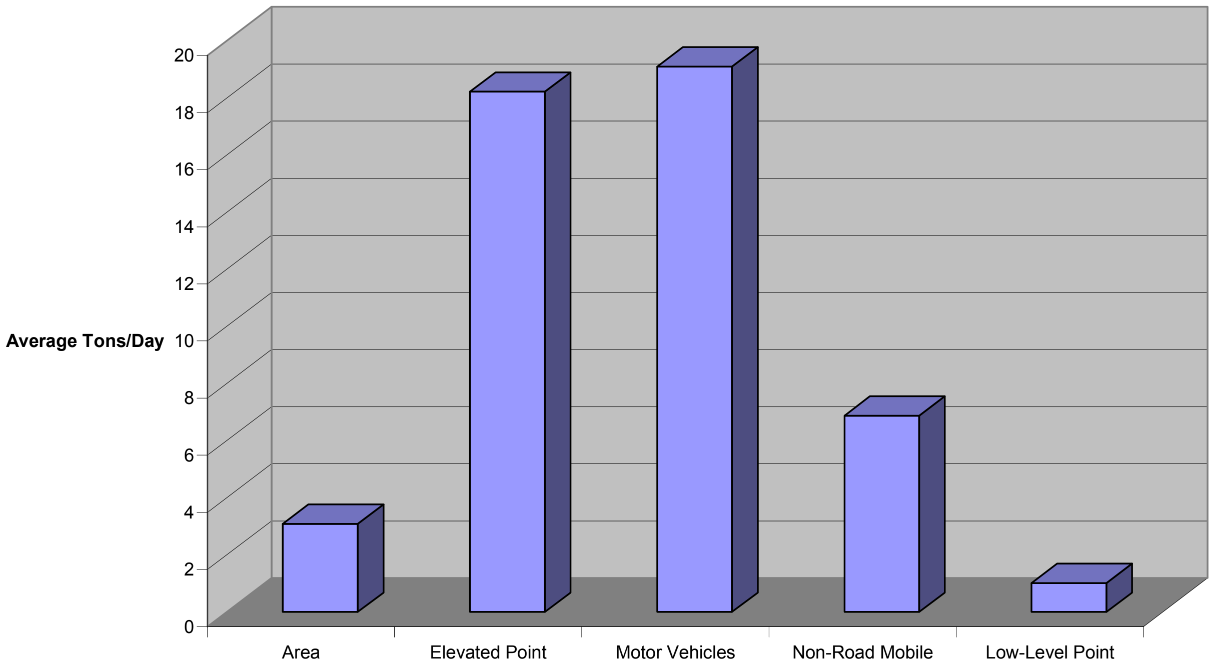


Figure 3-10d. Anderson area VOC 1998 Episode Emissions

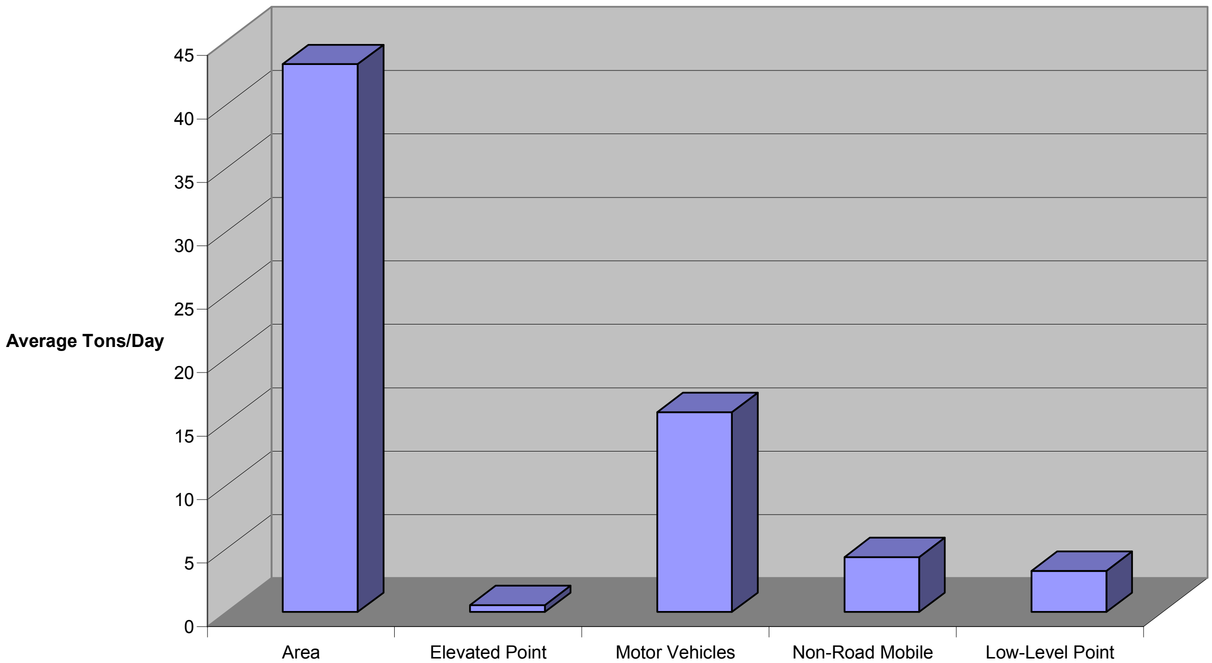


Figure 3-10e. Greenville area NOx 1998 Episode Emissions

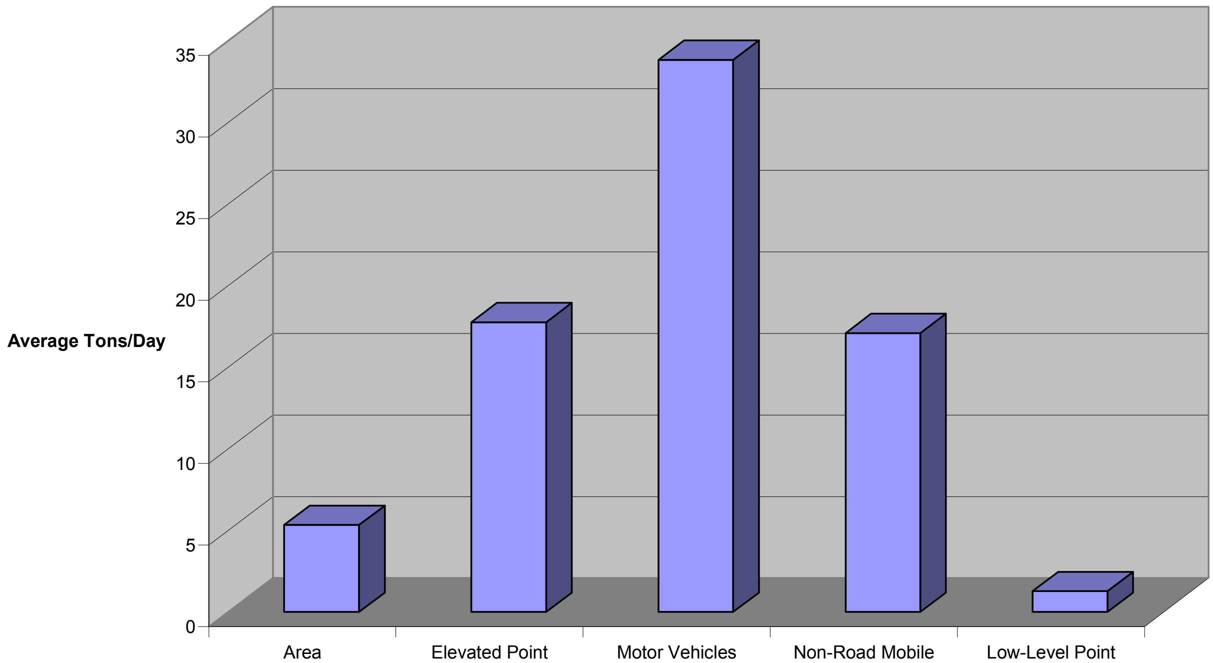


Figure 3-10f. Greenville area VOC 1998 Episode Emissions

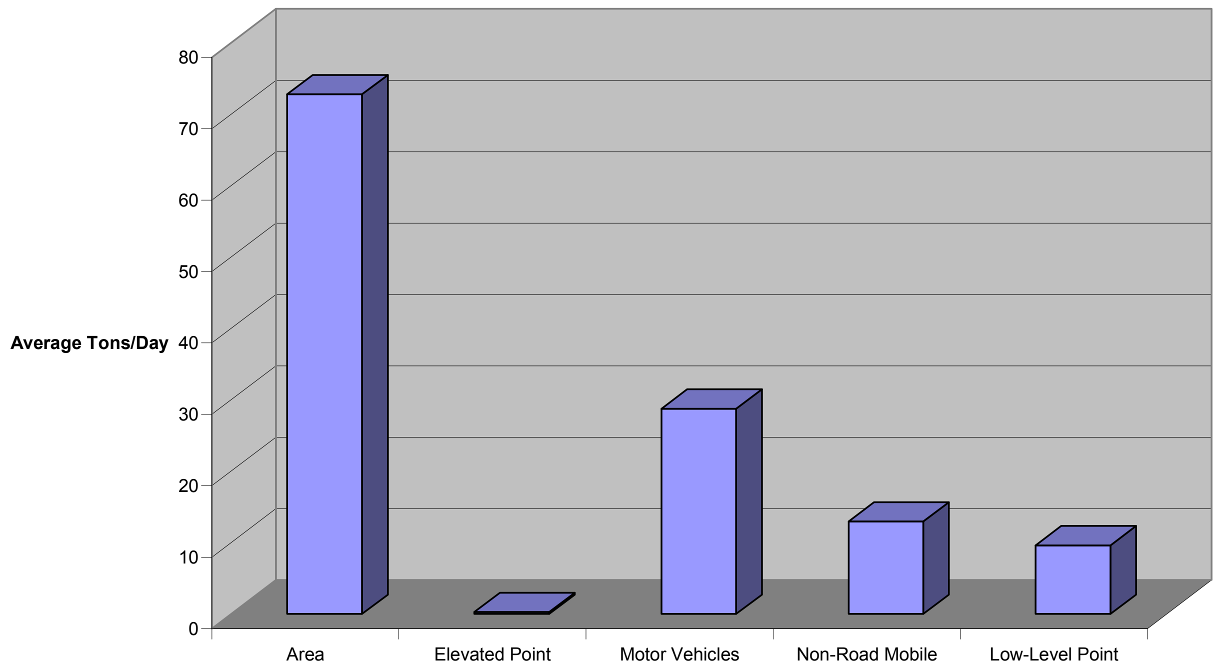


Figure 3-10g. Spartanburg area NOx 1998 Episode Emissions

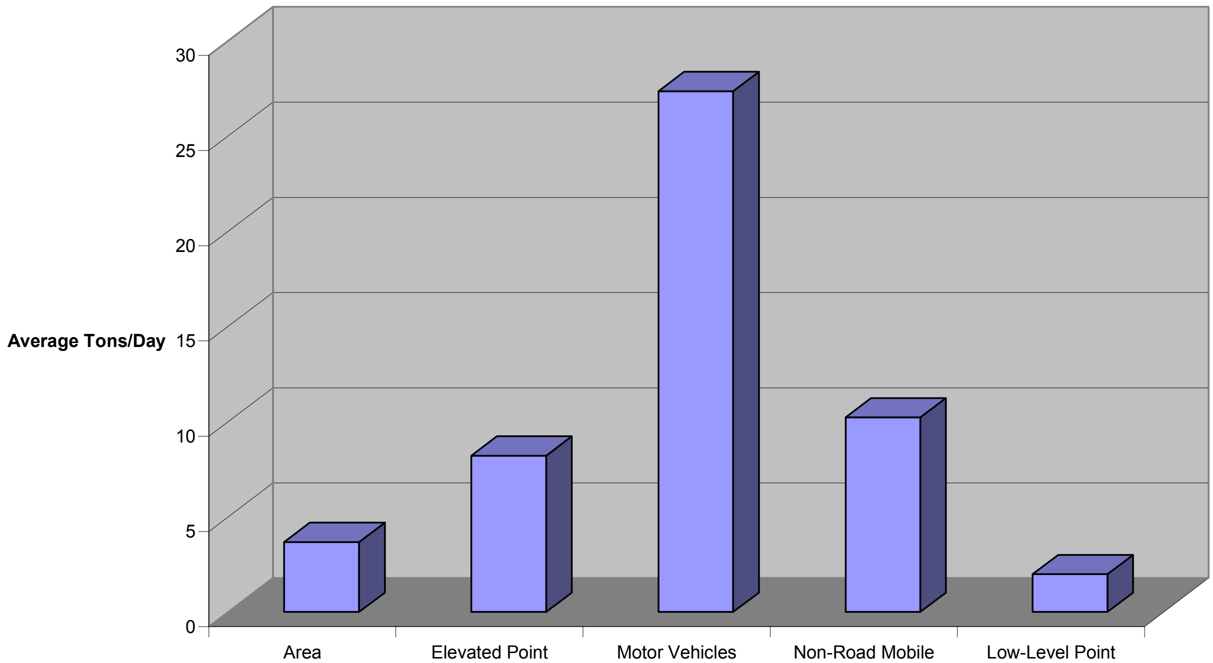


Figure 3-10h. Spartanburg area VOC 1998 Episode Emissions

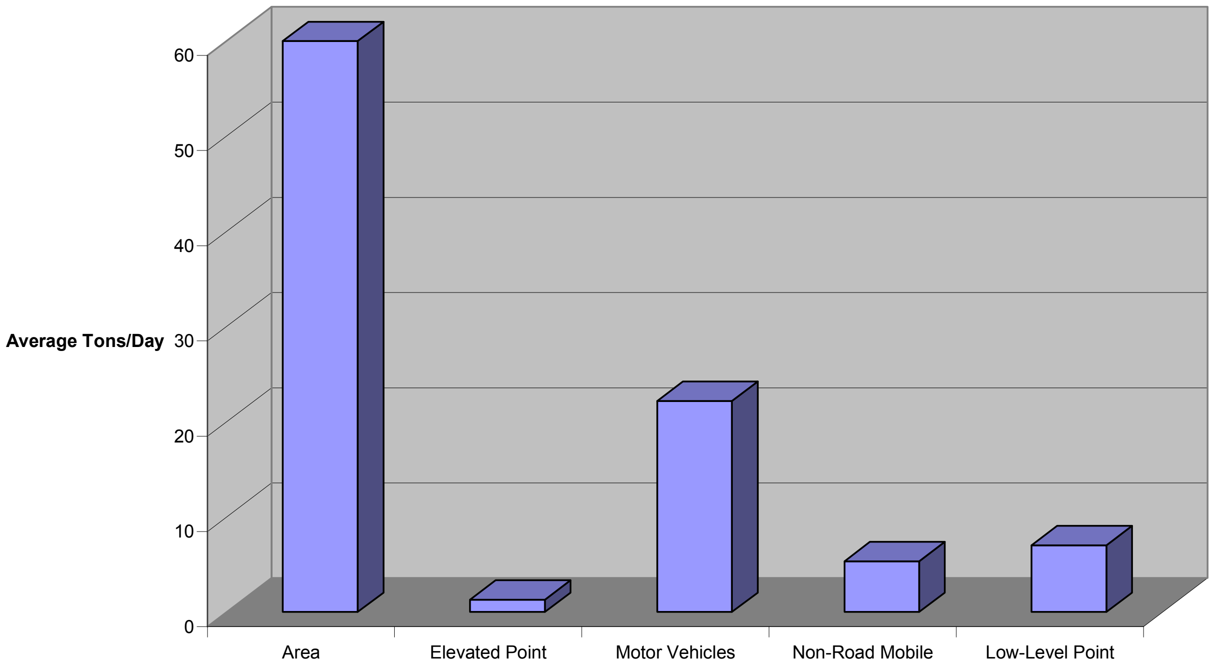


Figure 3-10i. Columbia area NOx 1998 Episode Emissions

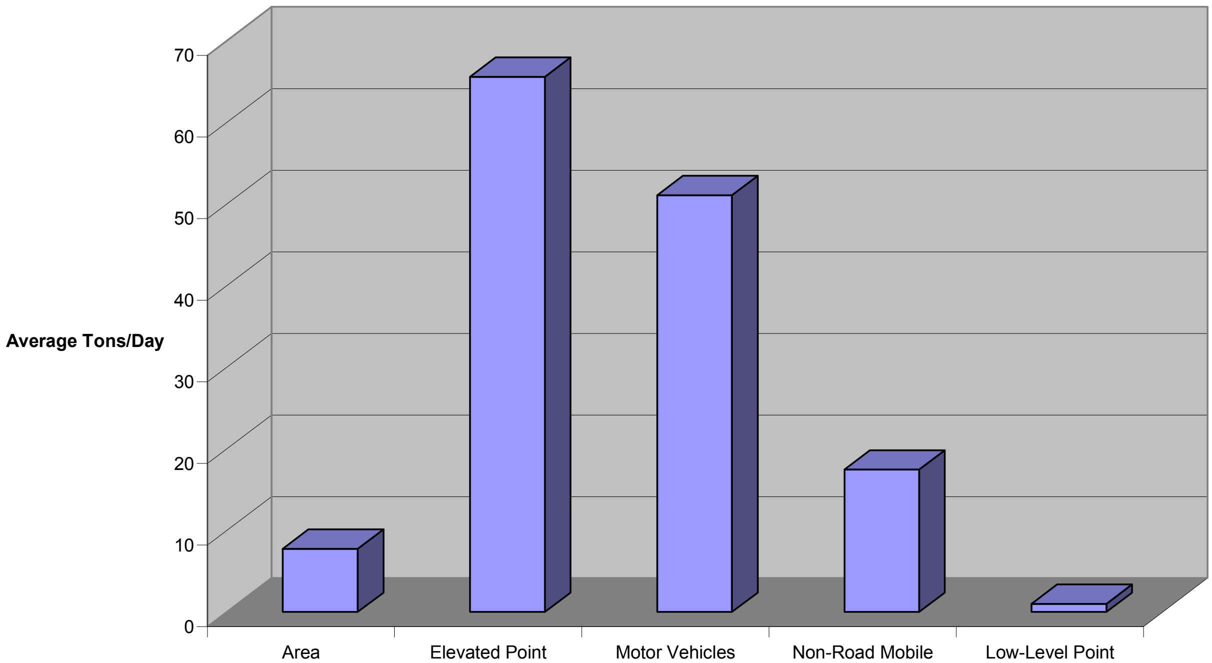
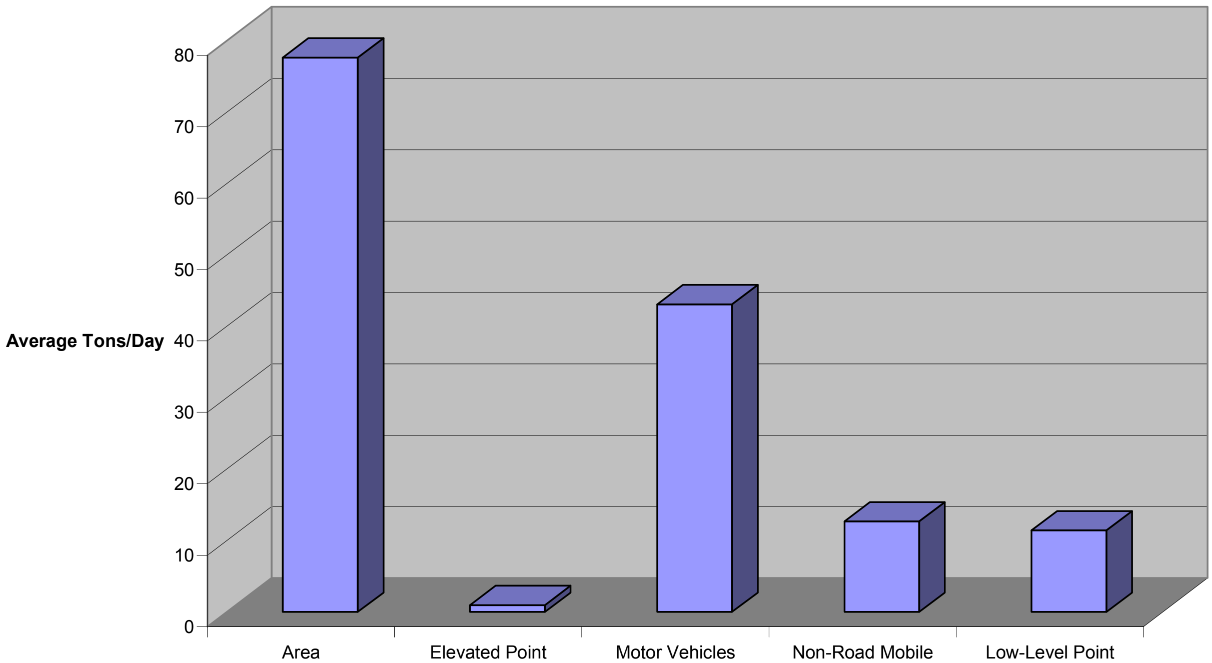


Figure 3-10j. Columbia area VOC 1998 Episode Emissions



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IV. Meteorological Modeling and Input Preparation

The UAM-V photochemical model requires hourly, gridded input fields of wind, temperature, water-vapor concentration, pressure, vertical exchange coefficients (K_v), cloud cover, and rainfall rate. These meteorological inputs were prepared for the South Carolina UAM-V application using the Pennsylvania State University/National Center for Atmospheric Research (PSU/NCAR) Mesoscale Model, Version 5 (MM5).

MM5 is a state-of-the-science dynamic meteorological modeling system that has been used in several previous air quality modeling applications. Key features of the MM5 modeling system that are relevant to its use in this study include multiple nested-grid capabilities, incorporation of observed meteorological data using a four-dimensional data-assimilation technique, detailed treatment of the planetary boundary layer, and the ability to accurately simulate features with non-negligible vertical velocity components, such as the sea breeze (a non-hydrostatic option). The MM5 modeling system is widely used and is currently supported by NCAR.

This section of the report contains an overview of MM5, the application procedures used, and the results obtained for this study. For ease of reading, all figures are presented following the text of this section.

A. Overview of the MM5 Meteorological Modeling System and Application Procedures

A general description of this three-dimensional, prognostic meteorological model is found in Anthes and Warner (1978); many of the newer features are described by Dudhia et al. (2001). The governing equations include the equations of motion, the continuity equations for mass and water vapor, and the thermodynamic equation. Those features relevant to this application are briefly described in this section.

Non-Hydrostatic Option

The current version of MM5 can be applied in a non-hydrostatic mode. This option improves simulation of small-scale vertical motions, such as those associated with the sea breeze and terrain effects. Because this can be important to the accurate simulation of airflow and other features at high horizontal resolution, the non-hydrostatic option was utilized for this study.

Modeling Domain

The MM5 modeling system supports the use of multiple nested grids. This feature is designed to enable the simulation of any important synoptic scale features at coarser resolution, while incorporating a high-resolution grid over the primary areas of interest. In this manner, the computational requirements associated with use of a high-resolution grid over a large domain are avoided. A one-way nesting procedure, in which information from the simulation of each outer grid is used to provide boundary conditions for the inner grids, is generally recommended and was used for this application.

The South Carolina MM5 modeling domain is presented in Figure 4-1. It consists of an extended outer grid with approximately 108 km horizontal resolution and three inner (nested) grids with approximately 36, 12, and 4 km resolution, respectively. A Lambert Conformal map projection was used for the application, to minimize the distortion of the grids within the area of interest. Information from the simulation of each outer grid provided boundary conditions for the inner grids. This one-way nesting procedure is the standard approach to nested-grid MM5 applications.

Vertical Coordinate System and Structure

The MM5 model employs the sigma vertical coordinate: $\sigma = (p - p_t)/(p_s - p_t)$, where p is pressure, p_t is the constant pressure specified as the top of the modeling domain, and p_s is the surface pressure. The sigma-coordinate surfaces follow the variable terrain. Twenty-two vertical levels were employed for this application such that the greatest vertical resolution was obtained within the boundary layer. The vertical layer structure is summarized in Table 4-1.

Table 4-1
MM5 vertical levels for the South Carolina application.

Level	Sigma	Average Height (m)
1	0.996	30
2	0.988	80
3	0.982	125
4	0.972	215
5	0.960	305
6	0.944	430
7	0.928	560
8	0.910	700
9	0.890	865
10	0.860	1115
11	0.830	1370
12	0.790	1720
13	0.745	2130
14	0.690	2660
15	0.620	3375
16	0.540	4260
17	0.460	5240
18	0.380	6225
19	0.300	7585
20	0.220	9035
21	0.140	10790
22	0.050	13355

The governing equations are integrated over a grid that is staggered in the horizontal and vertical (Messinger and Arakawa, 1976). In the horizontal, the u and v wind components are calculated at points that are staggered with respect to those for all other variables. In the vertical, vertical velocity is defined at the sigma levels while all other variables are defined at intermediate sigma levels.

Planetary Boundary Layer Treatment

To facilitate the realistic simulation of processes within the atmospheric boundary layer, variable surface parameters (including albedo, roughness length, and moisture availability) and a high-resolution planetary boundary layer (PBL) parameterization may be specified. For this study, the MRF high-resolution PBL scheme was employed. This scheme is compatible with the UAM-V formulation, and the requirements for specification of vertical exchange coefficients discussed below. This theoretical compatibility was also confirmed through sensitivity testing. Based on a series of tests using other of the PBL schemes, the vertical exchange coefficients derived using the MRF scheme produced the most realistic ozone levels and diurnal profiles. The PBL parameterization also requires use of a multi-layer soil temperature model, an otherwise optional feature of MM5.

Convective Parameterization

Several cumulus parameterization schemes are available in MM5 to parameterize the effects of convection on the simulated environment. Several explicit moisture schemes are available for high-resolution grids. For the coarser grids specified for this application, the Kain-Fritsch cumulus parameterization scheme (Kain and Fritsch, 1990) was used to parameterize the effects of convection on the simulated environment. This feature was not employed for the high-resolution (4-km) grid where an explicit moisture scheme (stable precipitation) was used.

Data Assimilation

The MM5 model supports four-dimensional data assimilation (FDDA), a procedure by which observed data are incorporated into the simulation. FDDA options include (1) “analysis nudging” in which the simulation variables are relaxed or “nudged” toward an objective analysis that incorporates the observed data and (2) “obs nudging” in which the variables are nudged toward individual observations.

For this study, three-dimensional analysis nudging was used for all variables. The nudging coefficients were specified to achieve weak nudging of the moisture fields (1×10^{-5}) and stronger nudging of the temperature and wind fields (2.5×10^{-4} for the 108 through 12-km grids, and 1×10^{-4} for the 4-km grid) toward the observational analyses.

Calculation of Vertical Exchange Coefficients

The MM5 modeling system was modified to include the output of the internally calculated vertical exchange coefficients (K_v). The K_v values are intended to represent non-local or multi-scale diffusion coefficients (rather than local diffusion coefficients) as described by Hong and Pan (1995). This information was used to specify the vertical exchange coefficients required by the UAM-V modeling system.

Initialization/Re-Initialization Scheme

For each simulation period, the model was initialized at 0000 GMT on the first day of the period. Thus, each MM5 simulation period includes a five-hour initialization period, before the output was used to prepare inputs for the UAM-V model. For the three outer grids, the MM5 was run continuously for the multi-day simulation period. For the higher-resolution grid, the model was reinitialized after each three days of simulation. Each re-initialization also included an additional 5-hour initialization period. Re-initialization was necessary to avoid the build up of non-meteorological noise in the simulation results that tended to occur after approximately 3 to 3 ½ days of simulation. The input fields from each simulation were inspected to ensure that piecing together the simulations did not create discontinuities in the meteorological inputs (the use of FDDA will alleviate this possibility). In any event, this occurred at midnight—a time that is not especially important in photochemical modeling.

Simulation Time Step(s)

The time step used for the simulations ranged from several minutes for the outermost (approximately 108 km) grid to 12 seconds for the innermost (approximately 4 km) grid.

MM5 Input Data

The data for preparation of the terrain, initial and boundary condition, and FDDA input files for this application were obtained from NCAR. The MM5 input files were prepared using the preprocessor programs that are part of the MM5 modeling system (Gill, 1992).

Meteorological data for the application of MM5 were also obtained from NCAR. These include the National Center for Environmental Prediction (NCEP) global analysis, and surface- and upper-air wind, temperature, moisture, and pressure data for all routine monitoring sites within the domain. The sites include National Weather Service (NWS) sites, buoys, and a few international monitoring sites. Sea-surface temperature data were also obtained from NCAR. These data comprise the standard data set for application of the MM5 modeling system, and were used for data assimilation as well as for the evaluation of the modeling results.

B. Preparation of UAM-V Ready Meteorological Fields

The meteorological modeling consisted of an initial application of the MM5 modeling system and two additional simulations using revised input parameters or application procedures. The meteorological modeling was a part of the overall UAM-V diagnostic analysis (as discussed in the following section).

Following the application of MM5, the simulation results were plotted and reviewed using a variety of graphical analysis tools. These included static plots of wind, temperature, specific humidity, vertical exchange coefficients, cloud cover, and rainfall, for selected domains, hours, and vertical levels as appropriate. The number and type of plots varied by episode, as needed to assess various aspects of the episode-specific meteorological conditions. The output was also examined using a view/animation graphics tool designed for use with MM5[3]. At this stage the MM5 results were also compared with observed wind, temperature, moisture, and cloud cover data—to identify geographical areas or time periods for which the model output did not represent the data well and as a check on the effectiveness of the data assimilation.

The MM5 output was then postprocessed to correspond to the UAM-V modeling domain and the units and formats required by the modeling system using the MM52UAMV postprocessing software. Wind, temperature, water-vapor concentration, pressure, vertical exchange coefficient, cloud-cover, and rainfall-rate input files containing hourly, gridded estimates of these variables were derived from the MM5 output. Surface temperature and solar radiation were postprocessed for use in preparing the mobile-source and biogenic emissions estimates.

[3] Environmental WorkBench, SSESCO, Minneapolis, MN.

C. Discussion of Procedures Used to Diagnose and Correct Problems and Improve Meteorological Fields

There are no specific criteria as to what constitutes an acceptable set of meteorological inputs for photochemical modeling. Throughout the course of the South Carolina modeling analysis, modifications were being made to the MM52UAMV postprocessing software for other applications, and updated versions of the software were applied to this project as they became available. A quick summary of the updates are listed here:

- The vertical diffusion coefficients were normalized, to ensure that the maximum value represented by MM5 was also represented in the UAM-V ready K_v fields.
- Similarity theory was applied to estimate surface wind speed, and average winds within the lowest UAM-V model layer.

A brief discussion of each of these follows.

For each horizontal grid cell, the vertical profile of the K_vs determines the diffusive mixing within the vertical column. For this application, hourly K_vs were output by MM5 for each horizontal grid cell and MM5 layer. These were then interpolated to the UAM-V layers (layer interface levels) for use by the photochemical model. To avoid excessive smoothing of the maximum MM5-derived K_v value (a possible result of interpolation), the K_v values were renormalized for each level based on the ratio of the MM5-derived maximum value and the interpolated maximum value. In this way, both the magnitude and vertical variation in K_v, as simulated by MM5, were retained in the UAM-V ready fields. In testing this technique, we found the difference between the interpolated and renormalized values to be greatest over varied terrain, where large K_v values are sometimes associated with terrain-induced vertical motions. Incorporating this modification into the meteorological inputs for the South Carolina application resulted in a slight increase in ozone at certain sites and a slight improvement in model performance. This modified postprocessing procedure was applied for all grids and was used to prepare the final base-case input fields.

Most applications of MM5, including this one, use for wind calculation a lowest layer that is approximately 30 to 40 m above ground level (this varies in accordance with the pressure-based sigma coordinate system). On the other hand, the lowest UAM-V layer is typically 50 m in thickness, and the wind speeds for this layer are intended to represent approximately 25 m above ground. For this application, the MM5-derived wind speeds were adjusted using similarity theory (e.g., as described by Panofsky and Dutton, 1984) to better represent the winds at the 25 m level. Similarity theory accounts for the effects of turbulence on atmospheric variables within the lowest portion of the atmospheric boundary layer, and thus provides a basis for estimating the wind speed profile within the surface layer. This profile is then used to adjust the MM5-derived speed so that it represents wind speed at the 25 m level. The result is a slight reduction in wind speed for the lowest UAM-V layer, instead of a straight mapping of the MM5 wind to this layer. For this application, the effects of the wind speed adjustment on the UAM-V simulated ozone concentrations were very small. Nevertheless, this approach represents a potentially improved use of the MM5 results, and so was used to prepare the final base-case input fields.

D. Presentation and Evaluation of MM5 Results

In this section we present the MM5 results corresponding to those that were used in the final UAM-V base-year (or base-case) simulation, as well as in the future-year simulation. The plots presented here were selected to illustrate the meteorological conditions associated with the modeling episode periods, and to provide information regarding the ability of the MM5 modeling system to represent some of the key meteorological features.

In presenting the results, we focus on wind, temperature, and vertical exchange coefficients—three key meteorological inputs for UAM-V (and, in the case of temperature, the emissions processing procedures). The domains and sites were selected to illustrate the key simulation features and the results for different areas within the domain, the areas of interest in particular. For the MM5 wind plots shown with observations, the display times were chosen based on observed data times or key hours relative to ozone activity (0700 EST for upper air plots and 1300 EST for surface plots). The MM5 plots are shown for all episode days.

To illustrate the evolution of the day-to-day wind patterns, UAM-V wind fields for both the surface and a selected upper level (approximately 1500 m) are shown for 1600 EST. This is generally around the time of maximum ozone concentration. The UAM-V ready wind fields are shown for all modeling episode days.

MM5 Upper-Level and Surface Wind Fields

The ability of the MM5 modeling system to represent the observed wind fields is illustrated for 16 - 23 May in Figures 4-2 and 4-3. Figure 4-2 gives the upper-level winds for approximately 1100 m agl for the 36-km resolution regional-scale grid (Grid 1 for MM5). The time 0700 EST was chosen to illustrate the upper level winds because radiosonde data are also available for this hour. The observed wind vectors are overplotted in bold. In general, the good agreement between simulated and observed winds indicates that the MM5 model replicates well the observed wind patterns for this level.

Surface layer wind fields (approximately 29 m agl) are plotted in Figure 4-3 for 1300 EST on the same days. This time was selected to illustrate the surface-level winds during the afternoon hours, typically just prior to the highest afternoon ozone concentrations. The domain shown in this figure is the 4-km MM5 domain. A southeasterly component dominates the winds over most of South Carolina on the 16th of May. A sea breeze is apparent in both the observation and the simulated fields in the vicinity of Charleston; elsewhere along the coastline the sea breeze appears to be overstated by the model. The clock-wise circulation of a high-pressure system off the coast of South Carolina is also evident. A stationary front is indicated over the central portion of South Carolina (and into North Carolina) on the 17th. Wind speeds and directions are well represented, including the convergence along the frontal zone. Winds over the northwestern part of the state are northeasterly, while those over the southeastern part of the state are southwesterly. A northeasterly component dominates the winds on the 18th. Again, wind speeds and directions are fairly well represented in the MM5 results, with a few exceptions. Very light winds characterize the wind patterns for the 19th, especially over the central portion of the state. This marks the transition to higher wind speeds and predominant westerly wind directions for the remainder of the simulation period. Over South Carolina, the surface winds are from the southwest on the 20th and from the west, veering to northwesterly, on the 21st. The model is a little slow in establishing this transition to northwesterly winds. Note the change in wind direction along the Atlantic coastline. Another weak front extending from northwest South Carolina to the coast is evident in the wind fields for 22 May. At the time shown in the plot, the modeled field appears to have the frontal system located slightly too far to the north (near the Georgia/South Carolina border). Winds on the 23rd are similar to those on the 21st. The influence of the Appalachian Mountain range is evident in many of the simulated fields. Observations in the influence zone of the mountains are not consistently represented in the simulation; agreement with the observations is sometimes good, sometimes not so good. Overall, the surface wind observations are well represented by MM5. The performance of the model in representing the surface winds tends to be least good in the northern part of this grid, especially under light wind conditions. Some of the best agreement with the observed data is achieved for sites in South Carolina. Surface wind speeds and directions over northern Georgia and North Carolina also tend to be fairly well represented, with an exception noted for North Carolina on the 22nd.

UAM-V Ready Wind Fields

The evolution of the regional-scale airflow patterns for the 16-23 May 1998 modeling episode period is illustrated in Figure 4-4 with once-daily (1600 EST) plots of the wind fields for layer 9 of the UAM-V model (approximately 1500 m agl). The regional-scale wind fields shown are for UAM-V Grid 1 (with approximately 36-km resolution). The wind fields show predominantly northwesterly wind components for the 16th, northerly components for the 17th, southerly components to the northwest of the Appalachian Mountains and northerly components to the southeast on the 18th, and clockwise circulation associated with high pressure centered over southern Georgia on the 19th, moving to the Gulf on the 20th. Winds on the 21st through the 23rd are predominantly from the west.

Surface-layer UAM-V ready wind fields for Grid 3 are shown in Figure 4-5 at 1600 EST. The wind fields show predominantly southwesterly wind components for the 16th, cyclonic flow on the 17th, northeasterly wind components for the 18th, southwesterly components on the 19th and 20th, and westerly components on the 21st. A front situated over the southeastern U.S. is indicated in the wind fields of the 22nd. On the 23rd, wind components are once again southwesterly.

MM5 Temperature Fields

MM5-derived surface temperatures are compared with observed values for several monitoring sites in the 4-km grid in Figure 4-6. The tendency for higher temperatures during the latter half of the modeling episode period is captured by MM5. However, MM5 tends to overestimate the maximum temperatures for most days at all sites. Noted exceptions are lower-than-observed temperatures for Augusta on the 20th, for Charleston and Columbia on the 22nd, and for Greenville on the 23rd. Note that for this comparison, the MM5-derived ground temperatures are compared with surface-layer measurement (typically for 5 m agl). Thus the MM5 temperatures are expected to be higher than the observations during the daytime hours and lower during the nighttime hours, as indicated in most of the plots.

MM5-Derived Vertical Exchange Coefficients

Finally, vertical profiles of the MM5-derived vertical exchange coefficients (K_v) are presented in Figure 4-7 for selected locations at 1300 EST for 16 - 23 May. As a general rule of thumb, the mixing height is approximately the level at which the value of K_v drops to ten percent of its maximum value. These profiles exhibit expected vertical distributions and indicate that the maximum effective mixing heights, when they are able to be determined, range from 500 to 1600 m during the episode at this time. On the 16th, mixing heights are relatively constant over the region, ranging from 1450 to 1600 m at the four sites. Mixing heights are lower on the 17th, ranging from 1100 to 1200 m at three of the four sites. Mixing heights at Augusta at this time on this day are undefined based on this technique. Mixing heights on the 18th are similar to those on the 16th and are approximately 1600 m at all four sites. Mixing heights on the 19th are also approximately 1600 m at three of the four sites, and approximately 1100 m at Columbia. Mixing heights on the 20th are undefined at Augusta by this technique, and are approximately 1550 m at the other three sites. Mixing heights on the 21st are once again approximately 1600 m at the four sites. On the 22nd, mixing heights are undefined at Columbia, and range from 500 m at Greenville, the northernmost site, to 1550 m at Charleston in the southeast. On the 23rd, the last day of the episode, mixing heights are undefined at Columbia and Greenville, and range from 1500 to 1600 m at Augusta and Charleston, respectively.

E. Quality Assurance of the Meteorological Inputs

The MM5 results were evaluated using mostly graphical analysis. The overall evaluation of the MM5 results included the following elements. For the outer grids, examination of the MM5 output focused on representation of the regional-scale meteorological features and airflow patterns, and included a comparison with weather maps. A more detailed evaluation of the results for the inner, high-resolution grid emphasized representation of the observed data, terrain-induced and other local meteorological features, and vertical mixing parameters. To the extent possible, the modeling results were compared with observed data. In the absence of data (e.g., for unmonitored areas and for not-measured parameters such as K_v), the MM5 results were examined for physical reasonableness as well as spatial and temporal consistency.

Comparison with the observed data was primarily used to examine the model's ability to represent key meteorological features such as wind speeds, wind directions aloft, and site-specific temperatures. The UAM-V ready meteorological inputs were also plotted and examined to ensure that the characteristics and features present in the MM5 output were retained following the postprocessing step. The ability of the MM5 model to reproduce observed precipitation patterns was qualitatively assessed by comparing simulated and observed rainfall patterns, using NWS data. Some rainfall occurred during the episode periods and this was reflected in the MM5.

The following graphical summaries were prepared to facilitate the review/evaluation of the meteorological inputs:

- 3-dimensional visualizations of the MM5 output using the Environmental WorkBench software (an enhanced version of VIS-5D)
- x-y cross-section plots of the MM5 wind fields for several levels and times, with observations overplotted for MM5 Grids 1, 2, and 3
- x-y cross-section plots of the UAM-V ready wind, temperature, vertical exchange coefficient, cloud cover, and rainfall-rate fields for several times and levels (as appropriate)

On two occasions during the course of modeling analysis, we enhanced the MM52UAM-V software for other applications, and re-processed the fields using enhanced versions of the software.

Finally, the process analysis feature of UAM-V was also used to further examine the role of the meteorological inputs in determining the simulated concentration patterns and levels and their contribution to good or poor model performance. The role of meteorology in the diagnostic analysis for UAM-V is discussed in more detail in Section 6.

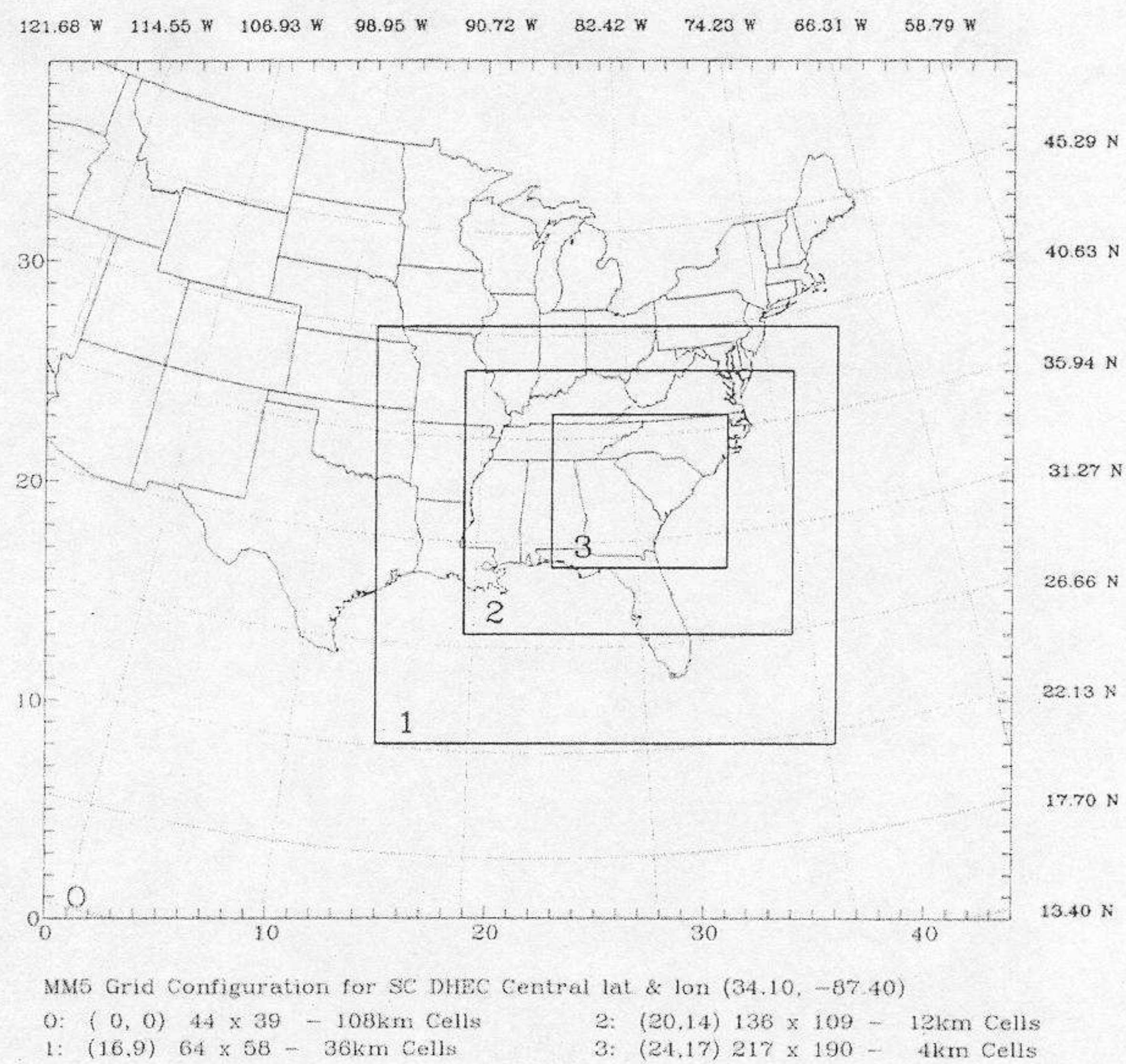

FIGURE 4-1
MM5 modeling domain for the South Carolina application.

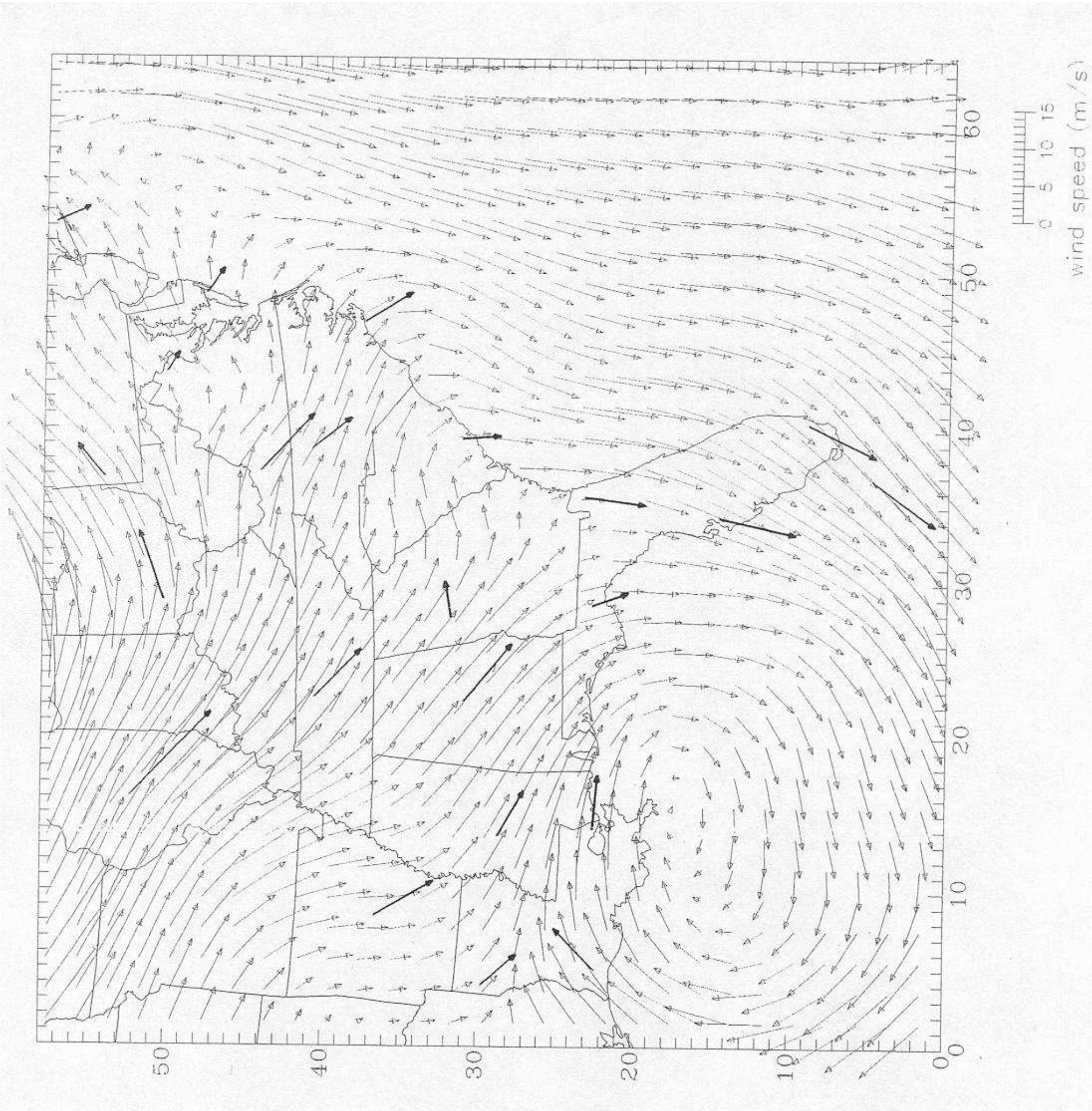

FIGURE 4-2(a). MM5 wind fields at 0700 EST on 16 May 1998 at 1068 m for the 36-km resolution SCDHEC grid.

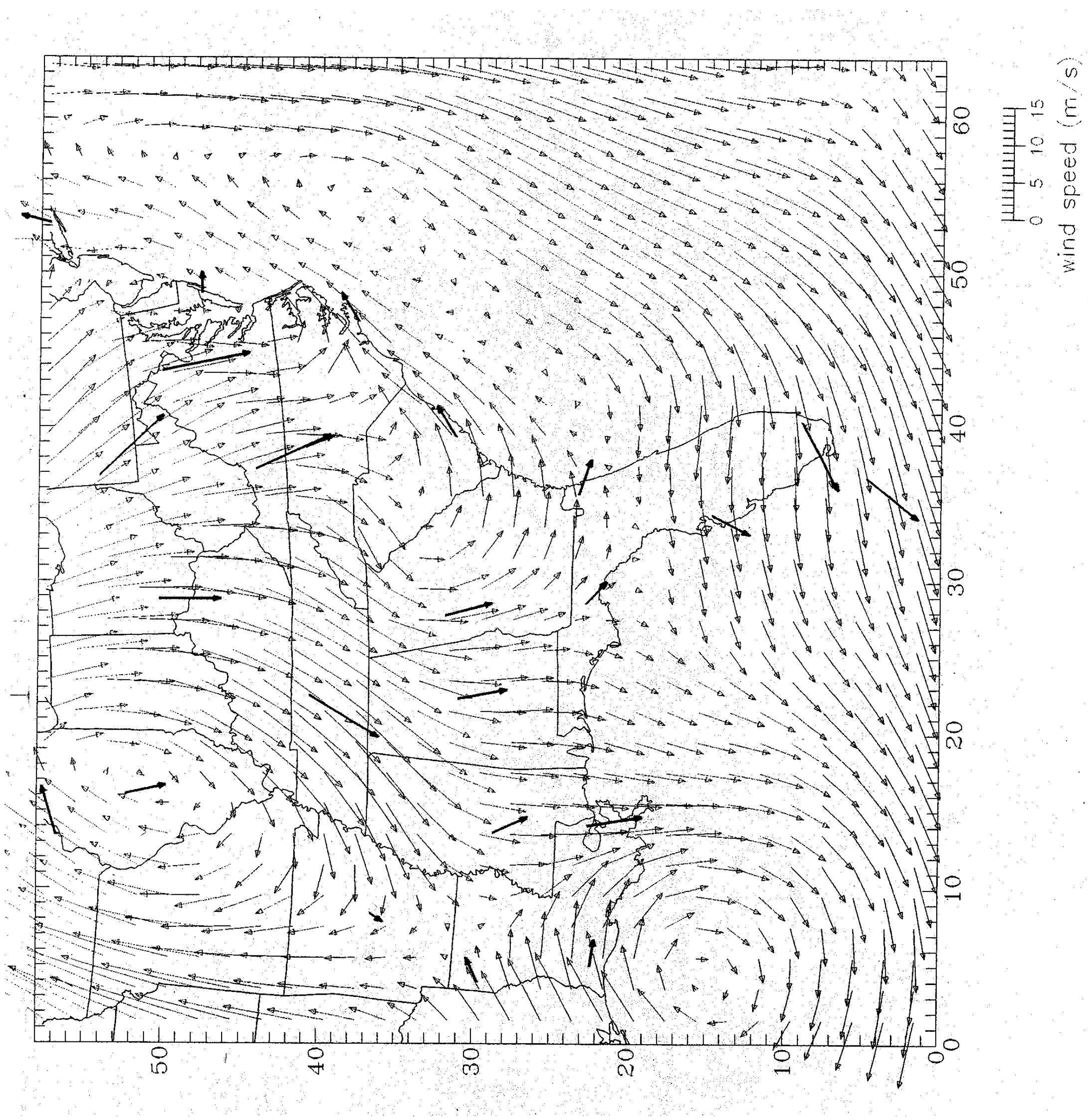

FIGURE 4-2(b). MM5 wind fields at 0700 EST on 17 May 1998 at 1068 m for the 36-km resolution SCDHEC grid.

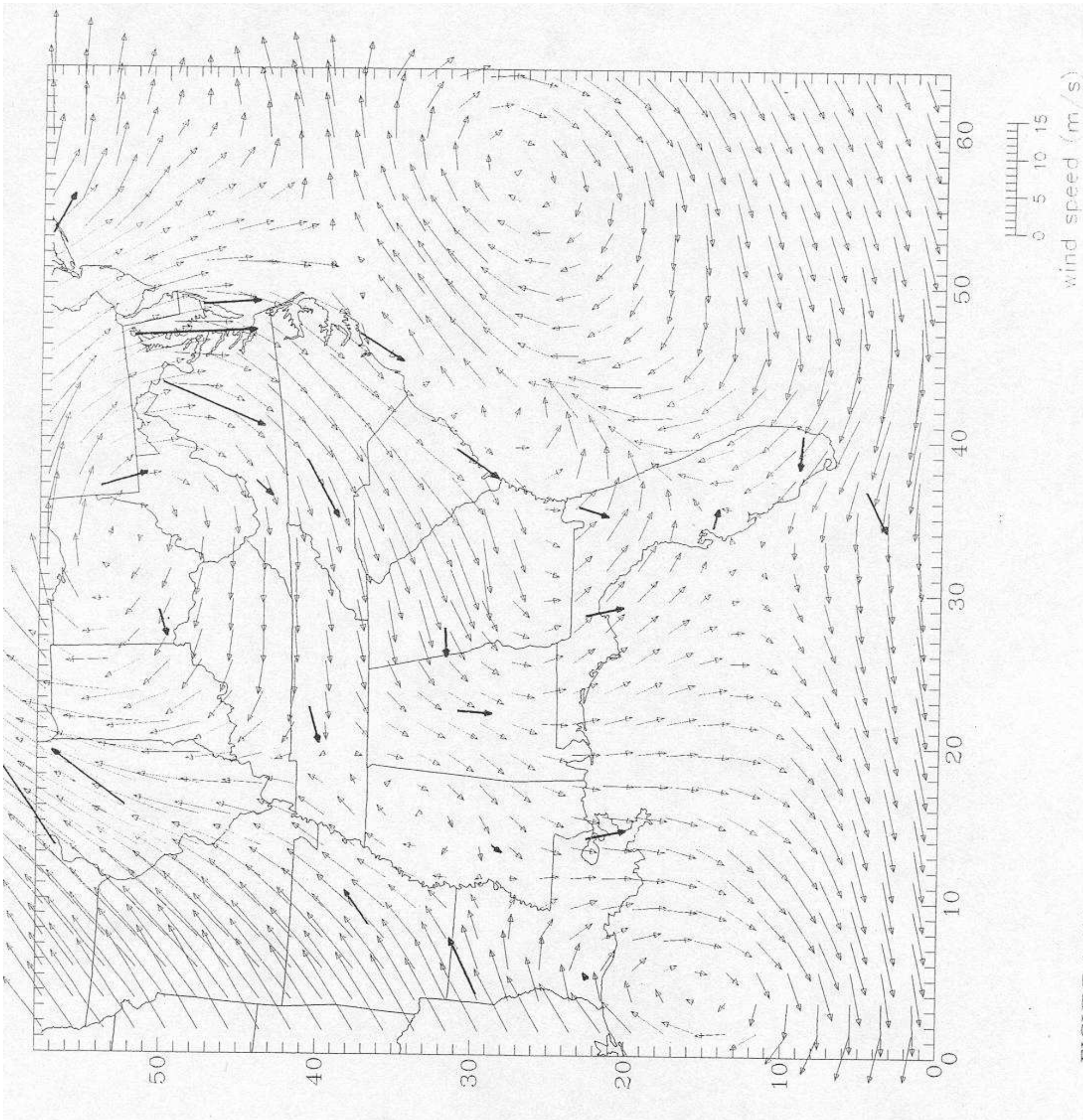

FIGURE 4-2(c). MM5 wind fields at 0700 EST on 18 May 1998 at 1068 m for the 36-km resolution SCDHEC grid.

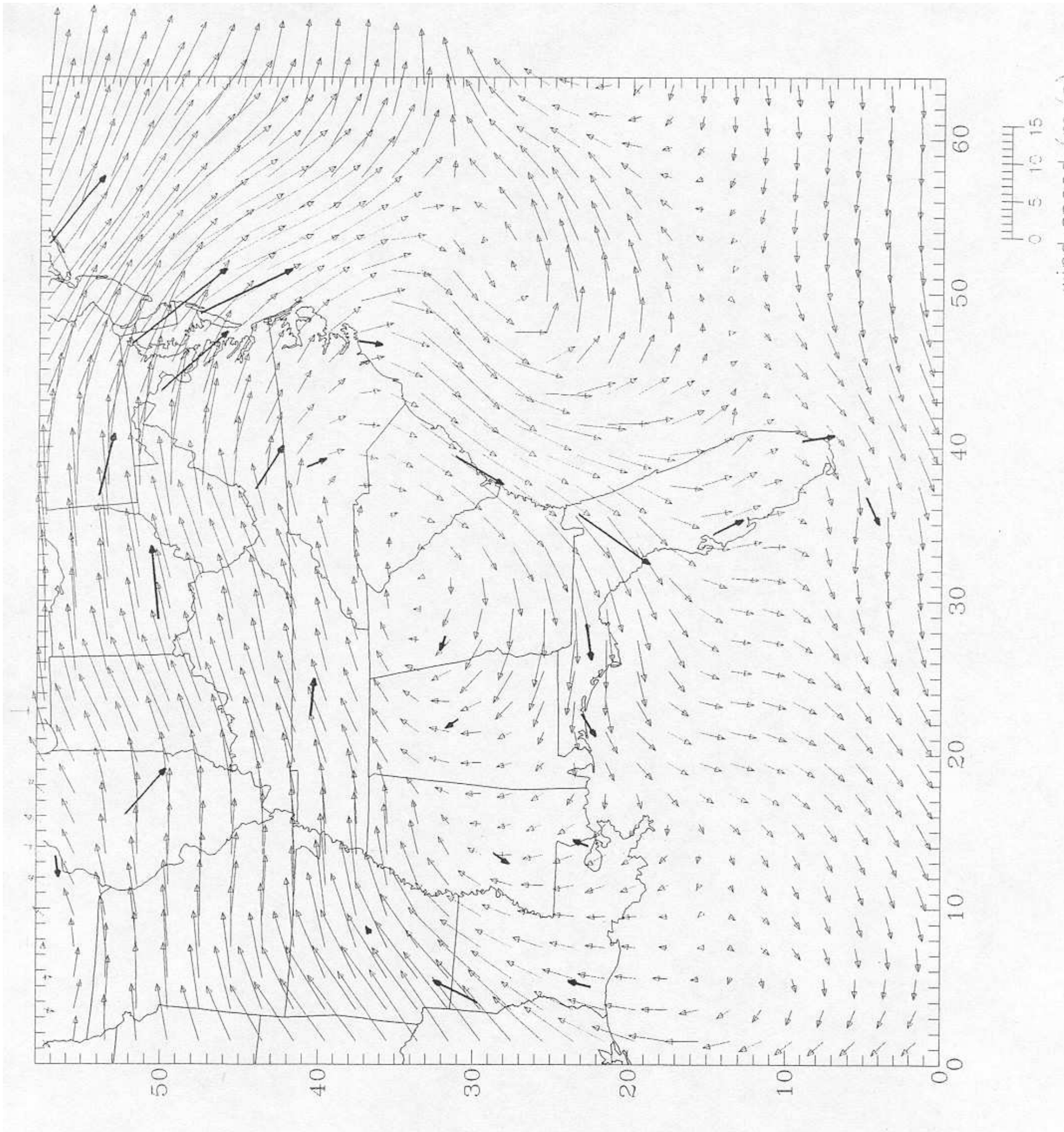

FIGURE 4-2(d). MM5 wind fields at 0700 EST on 19 May 1998 at 1068 m for the 36-km resolution SCDHEC grid.

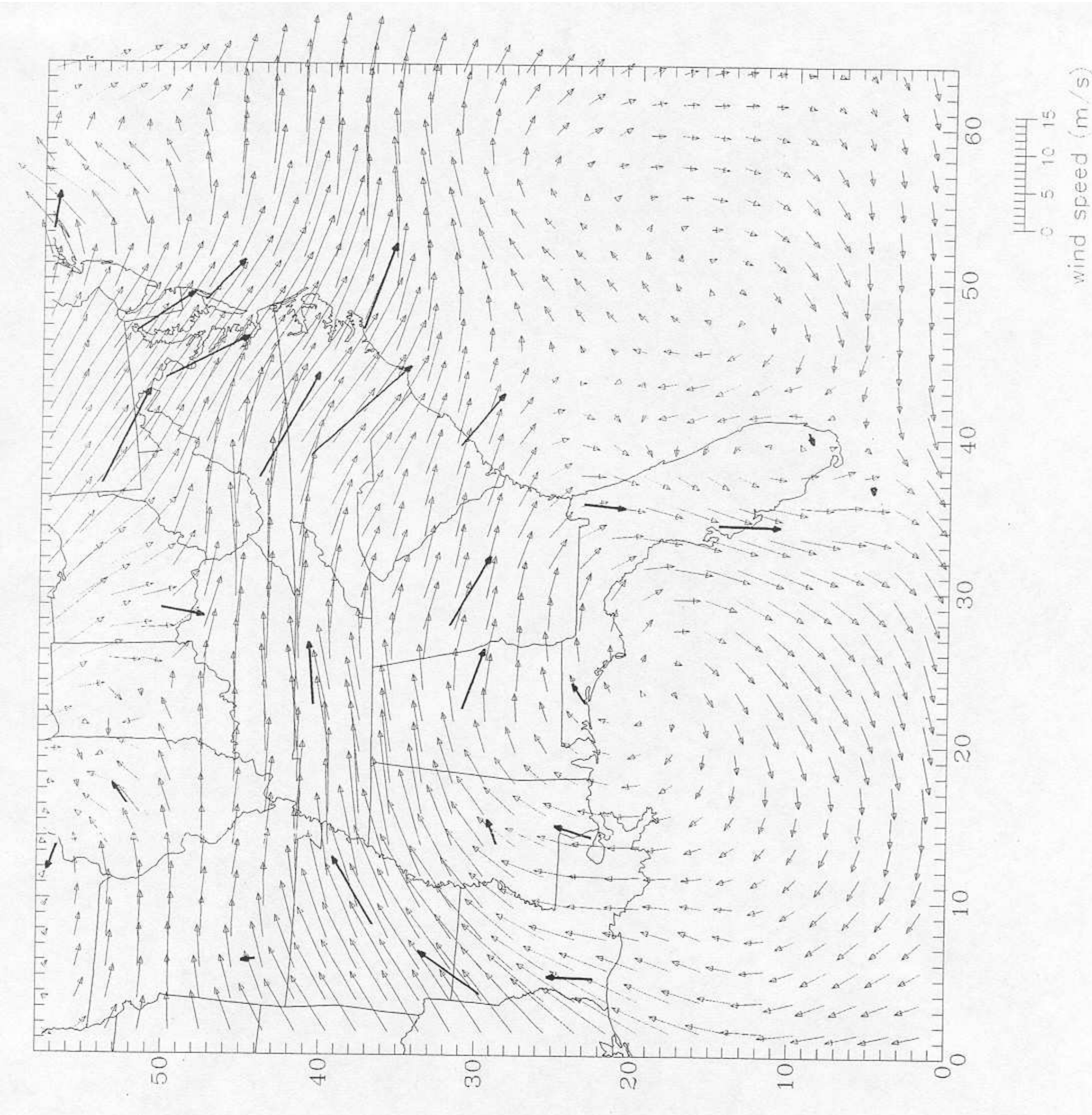

FIGURE 4-2(e). MM5 wind fields at 0700 EST on 20 May 1998 at 1068 m for the 36-km resolution SCDHEC grid.

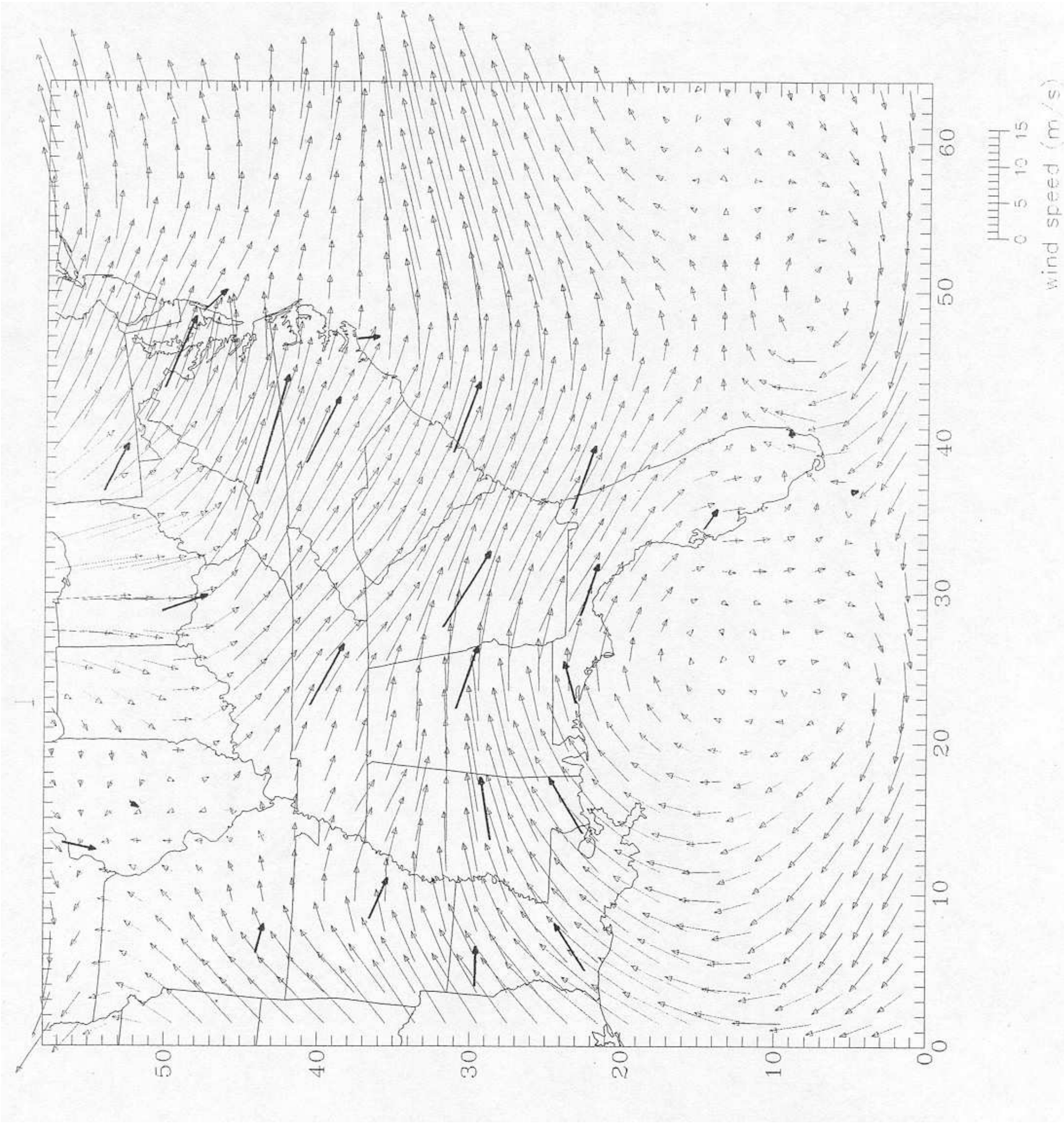

FIGURE 4-2(f). MM5 wind fields at 0700 EST on 21 May 1998 at 1068 m for the 36-km resolution SCDHEC grid.

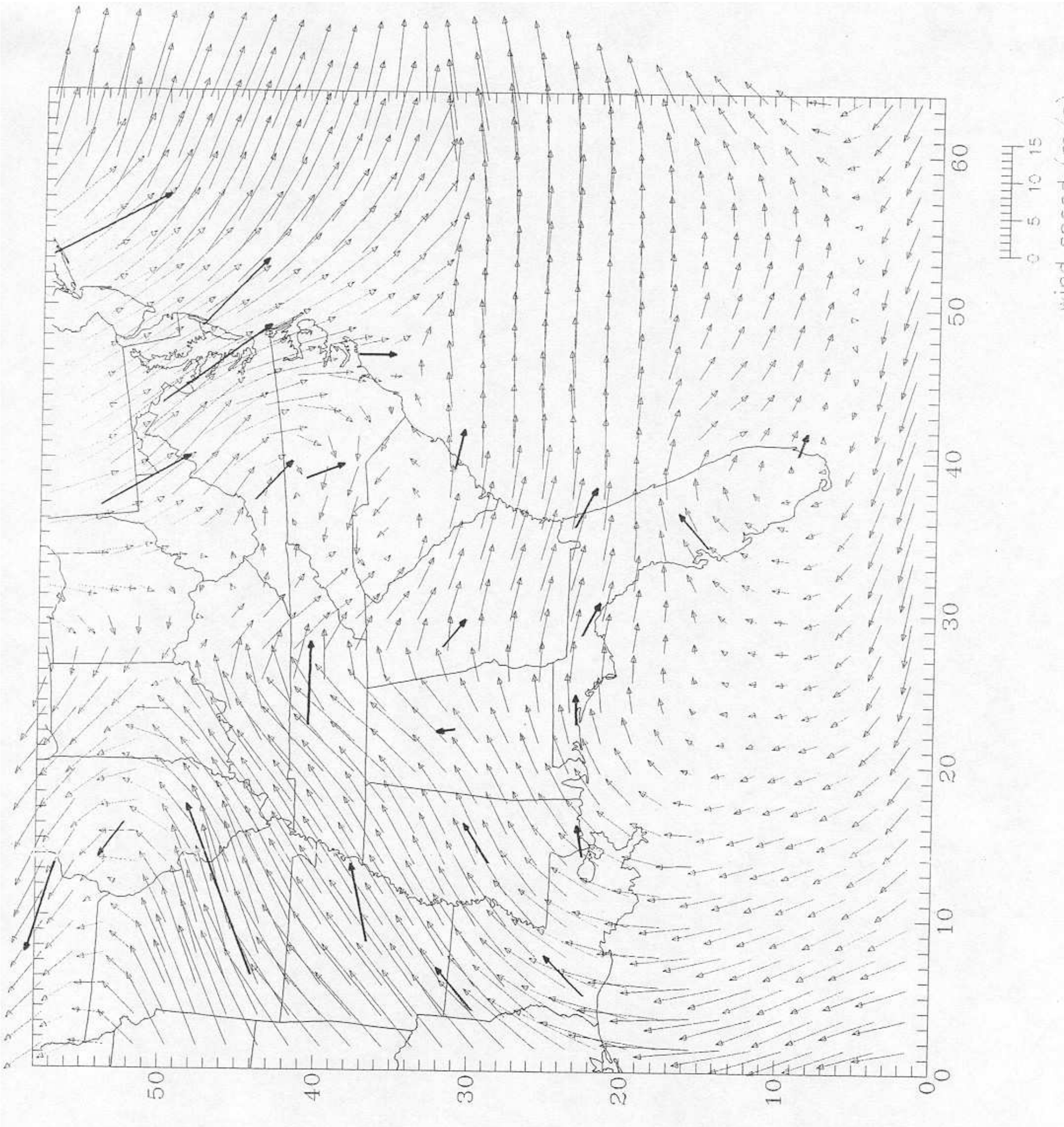

FIGURE 4-2(g). MM5 wind fields at 0700 EST on 22 May 1998 at 1068 m for the 36-km resolution SCDHEC grid.

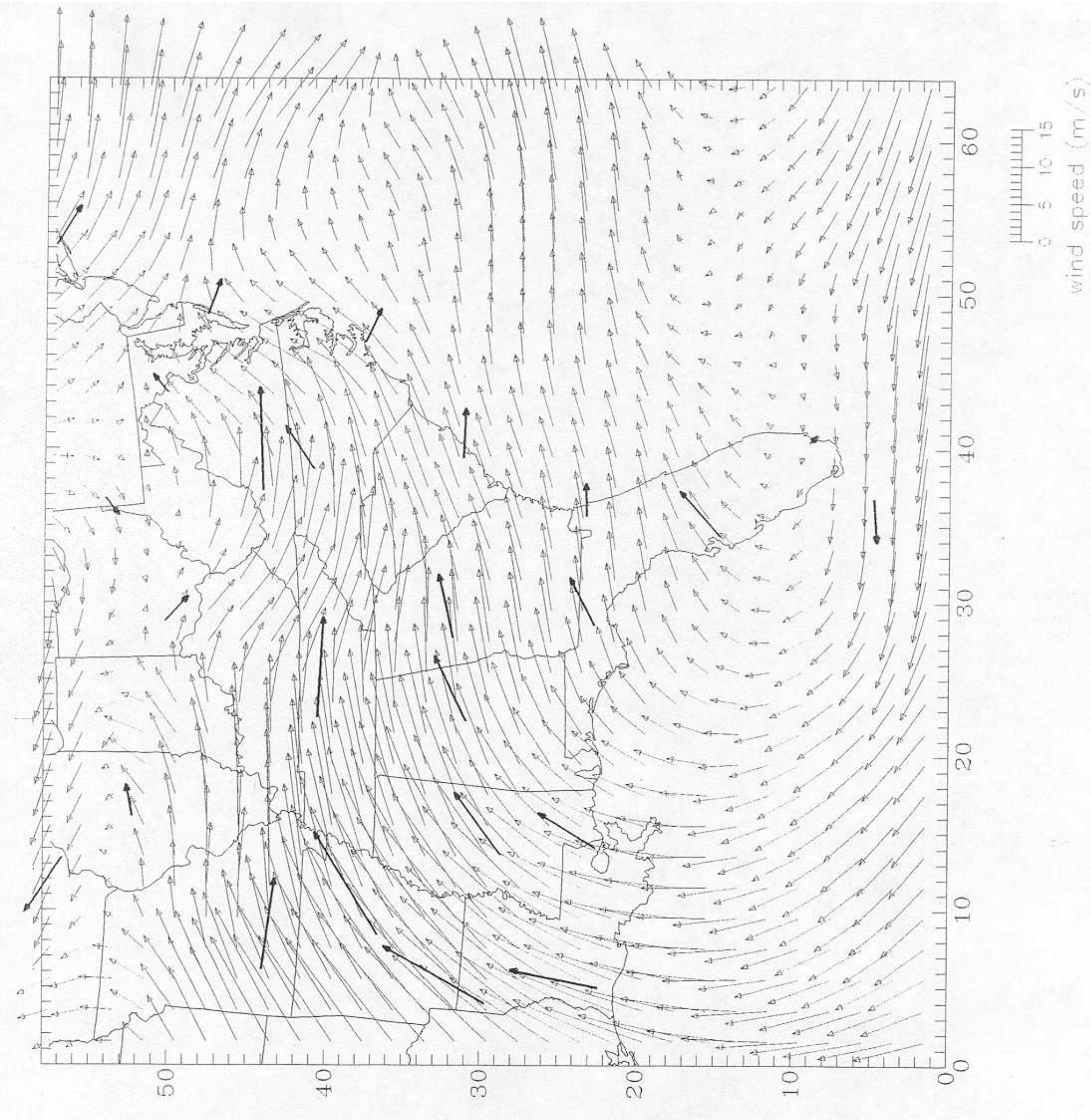

FIGURE 4-2(h). MM5 wind fields at 0700 EST on 23 May 1998 at 1068 m for the 36-km resolution SCDHEC grid.

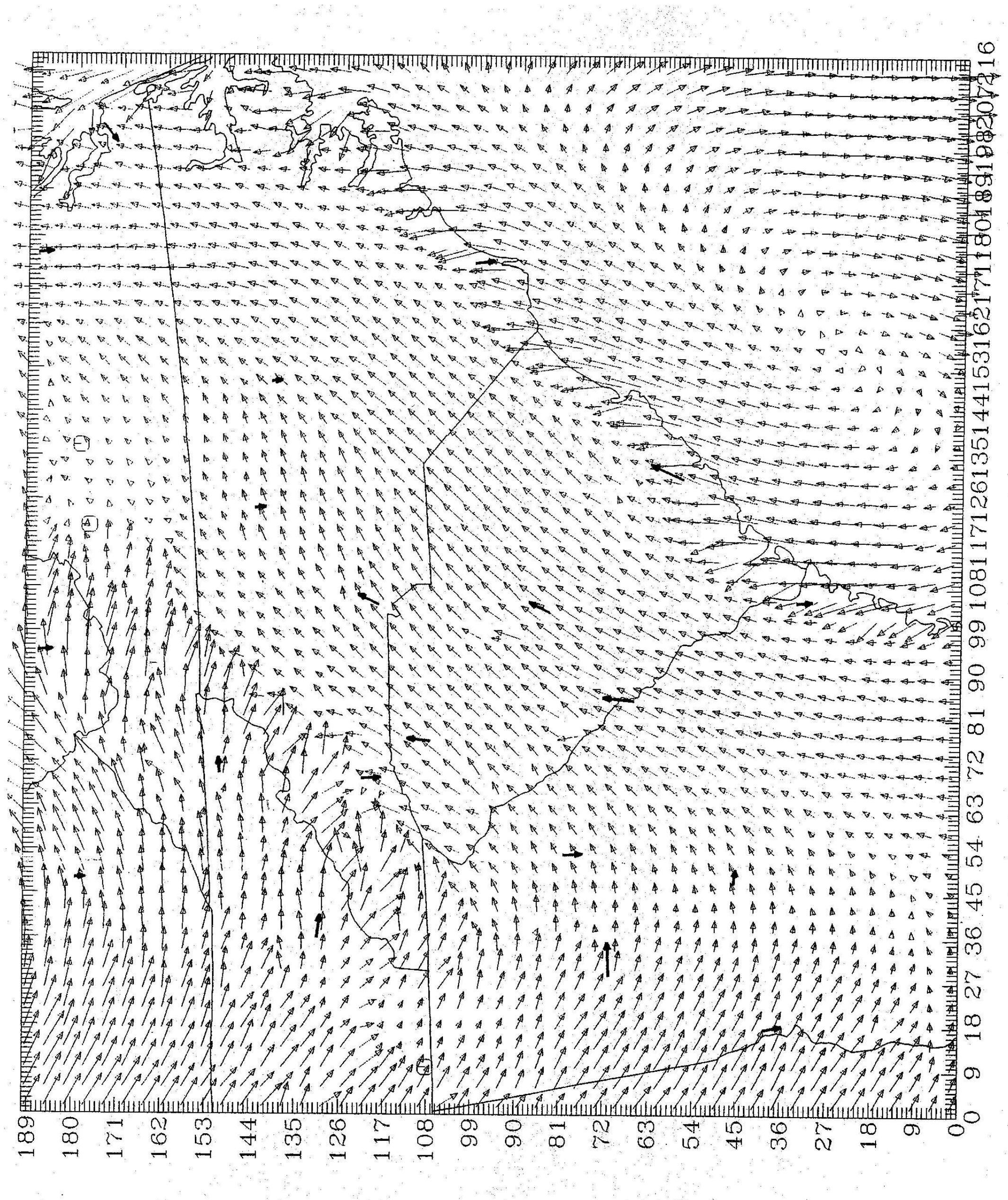

FIGURE 4-3(a). MM5 surface wind fields at 1300 EST on 16 May 1998 for the 4-km resolution SCDHEC grid.

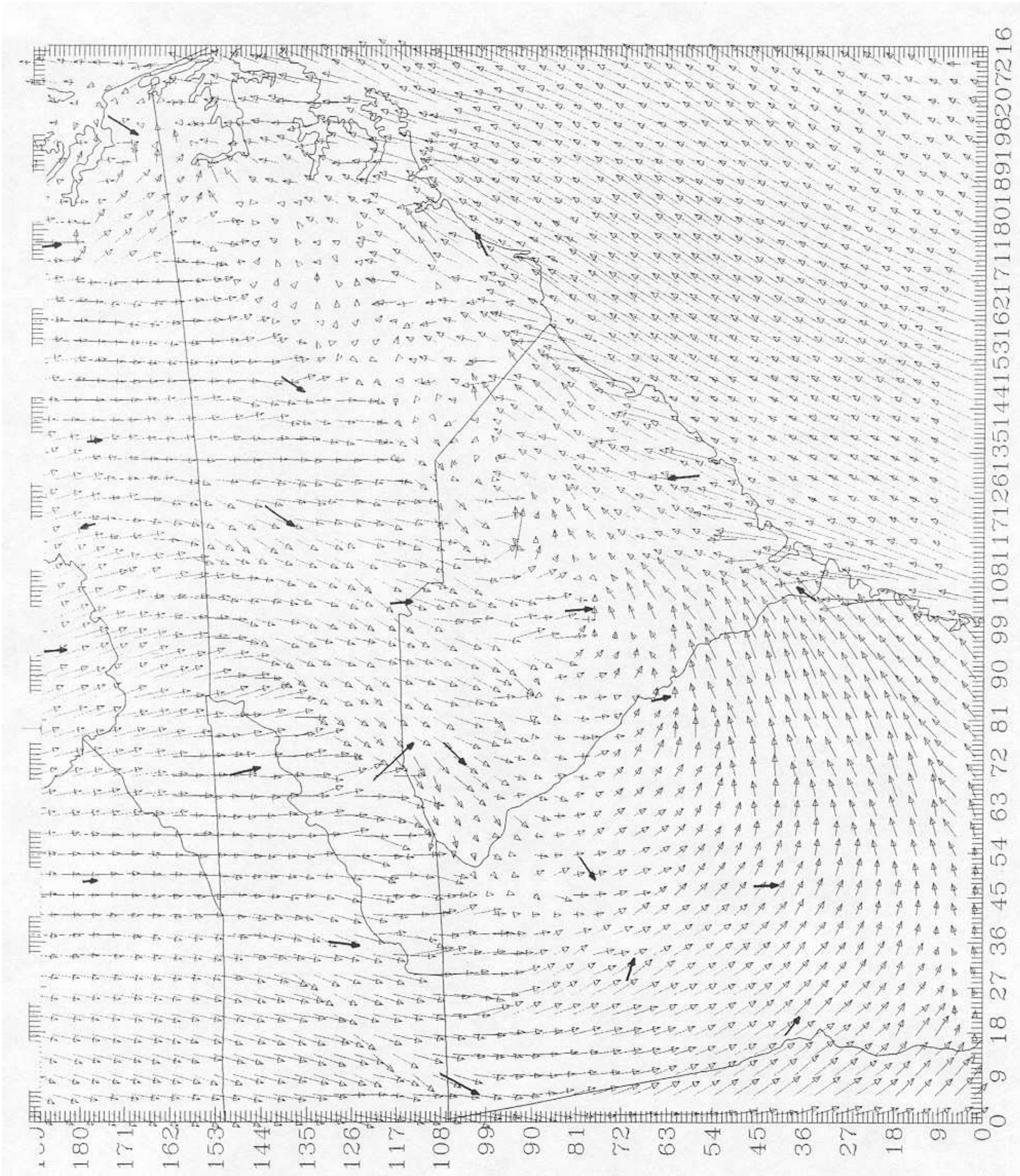

FIGURE 4-3(b). MM5 surface wind fields at 1300 EST on 17 May 1998 for the 4-km resolution SCDHEC grid.

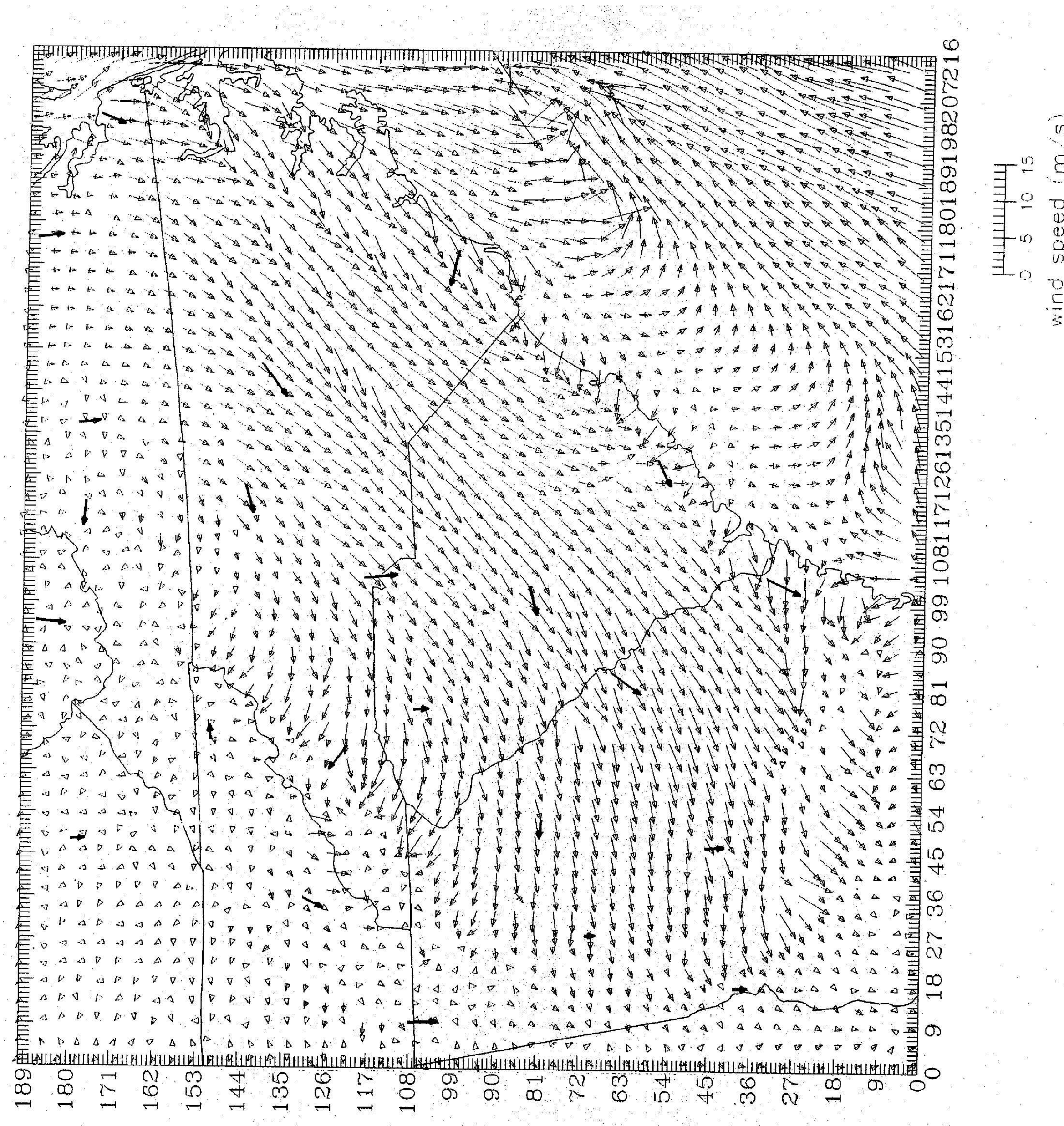

FIGURE 4-3(c). MM5 surface wind fields at 1300 EST on 18 May 1998 for the 4-km resolution SCDHEC grid.

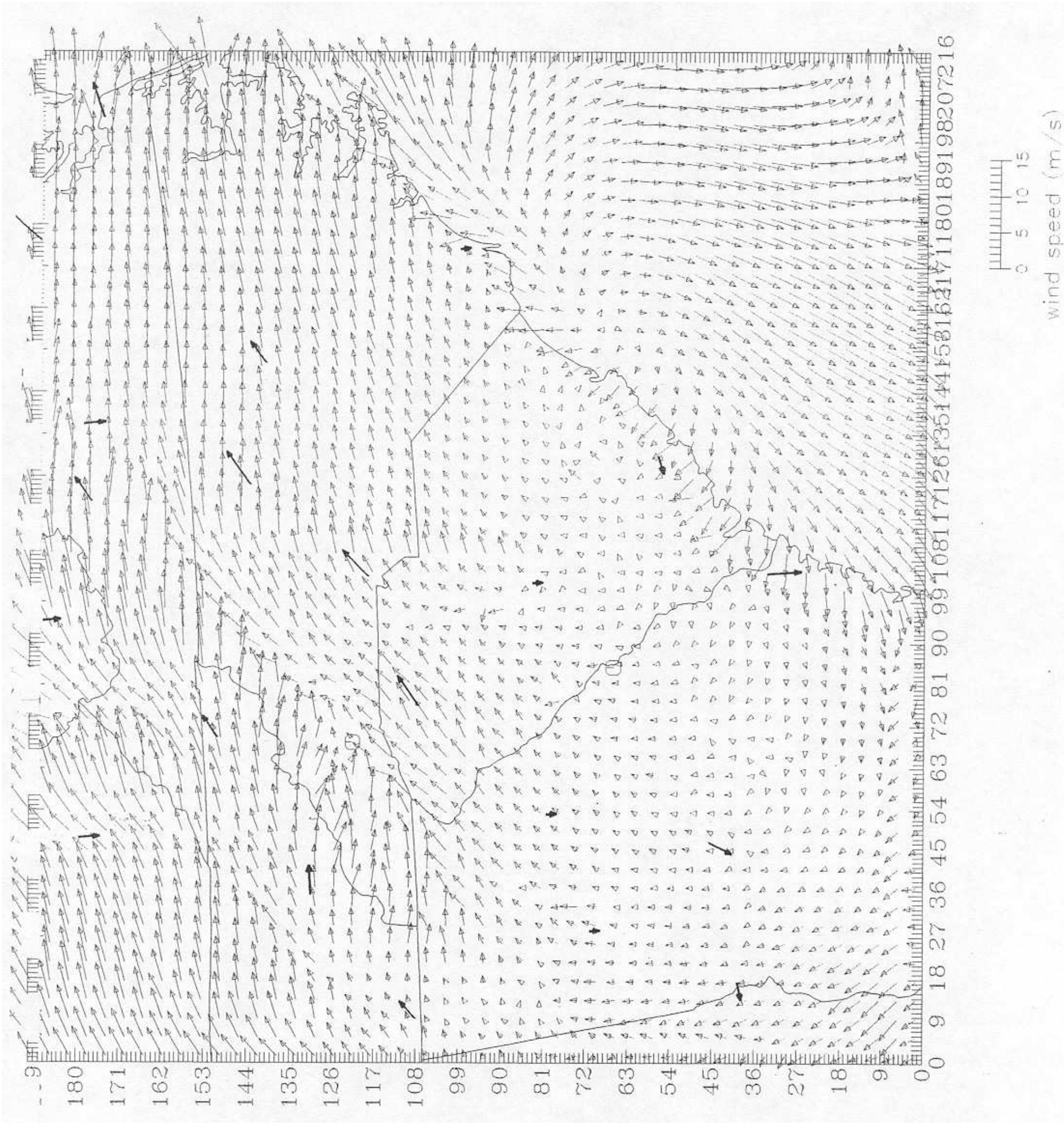

FIGURE 4-3(d). MM5 surface wind fields at 1300 EST on 19 May 1998 for the 4-km resolution SCDHEC grid.

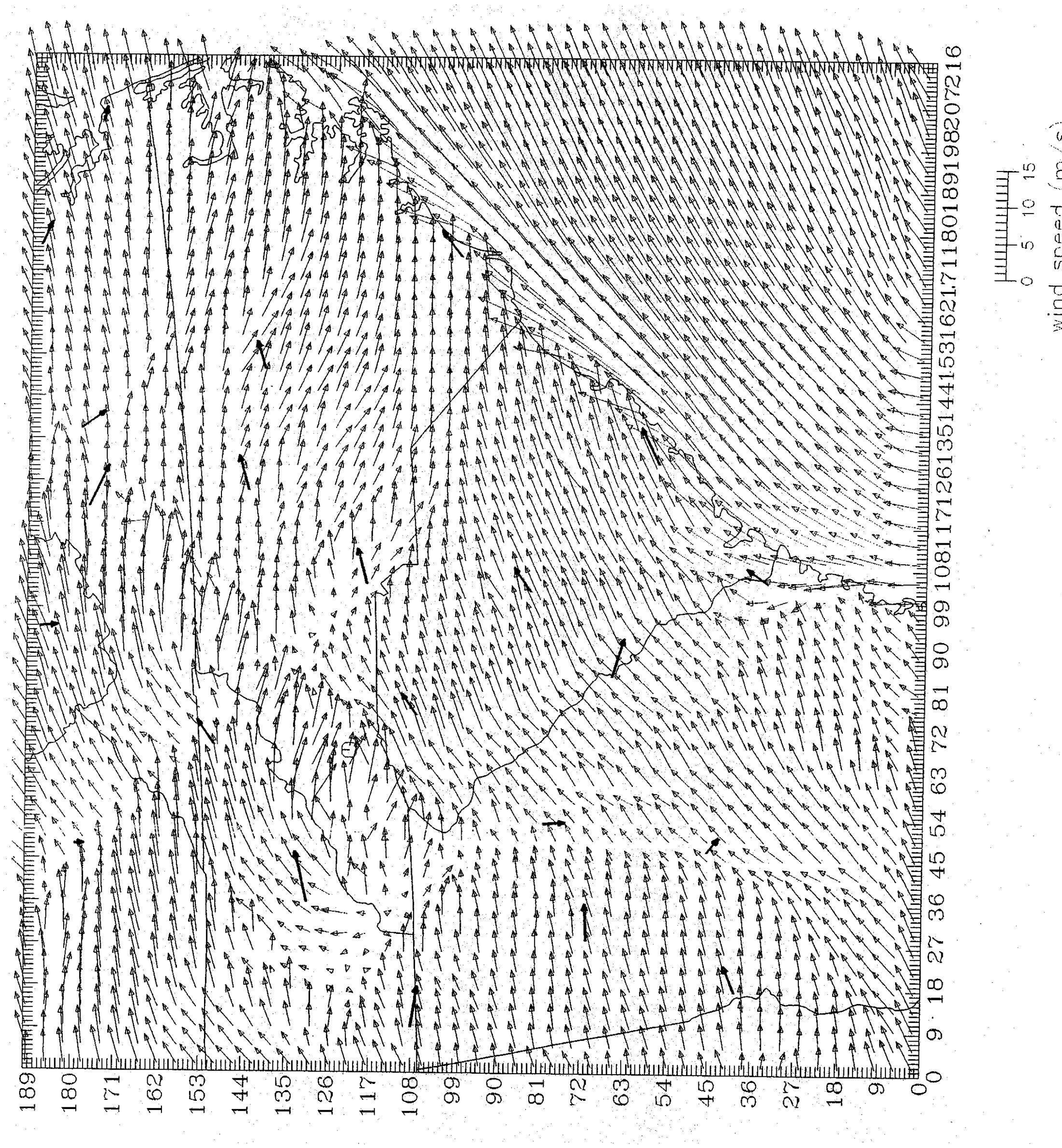

FIGURE 4-3(e). MM5 surface wind fields at 1300 EST on 20 May 1998 for the 4-km resolution SCDHEC grid.

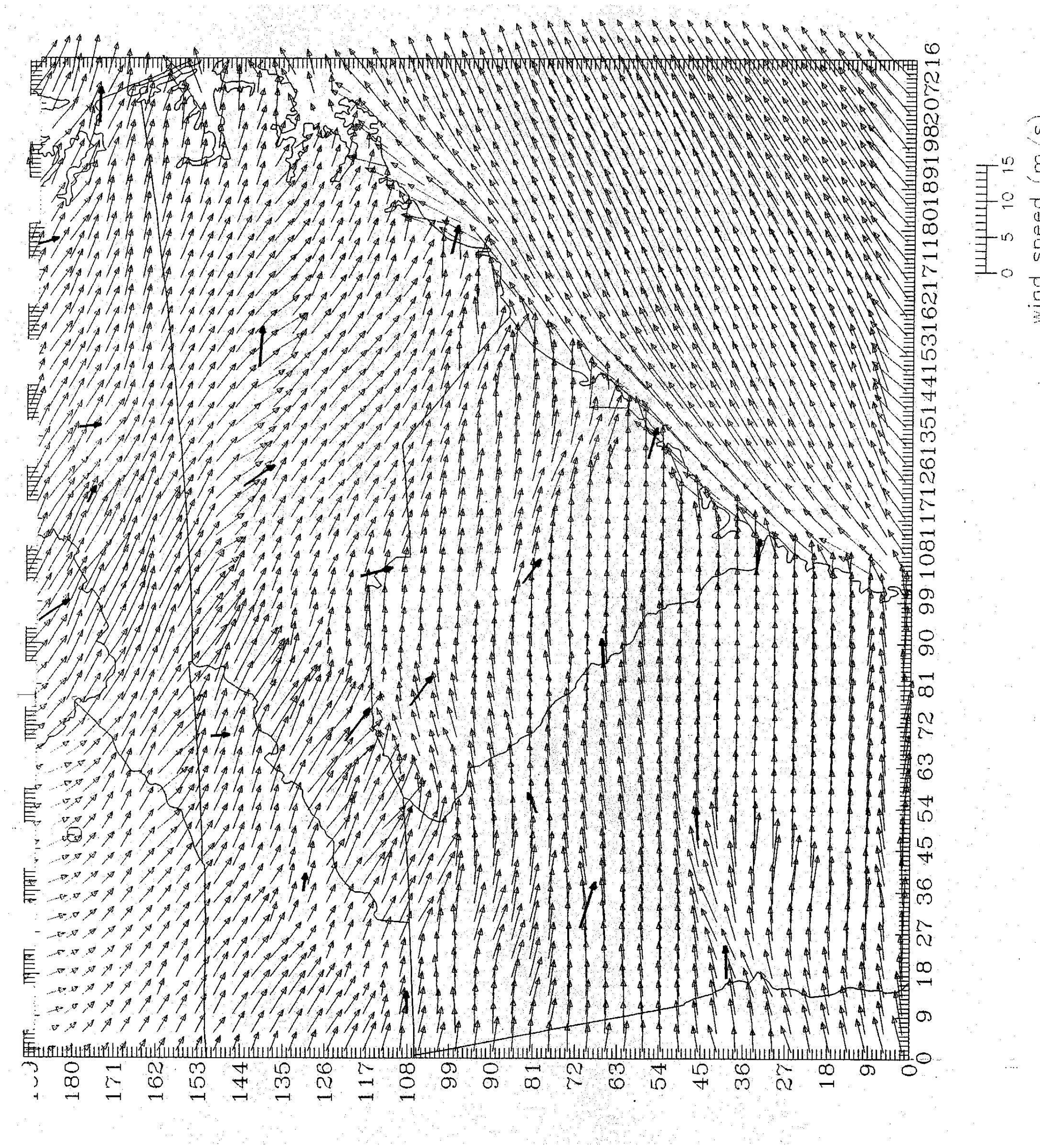

FIGURE 4-3(f). MM5 surface wind fields at 1300 EST on 21 May 1998 for the 4-km resolution SCDHEC grid.

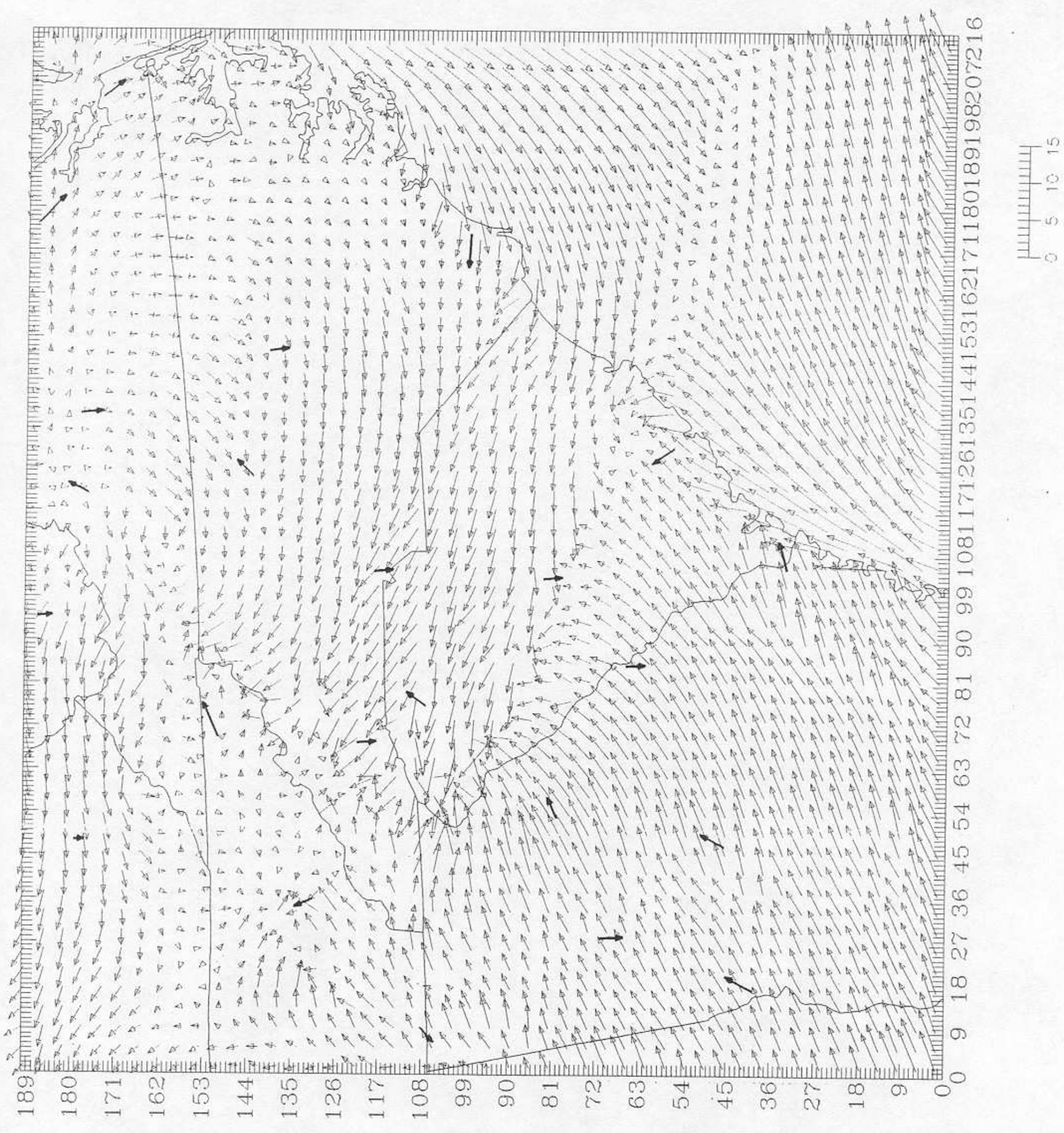

FIGURE 4-3(g). MM5 surface wind fields at 1300 EST on 22 May 1998 for the 4-km resolution SCDHEC grid.

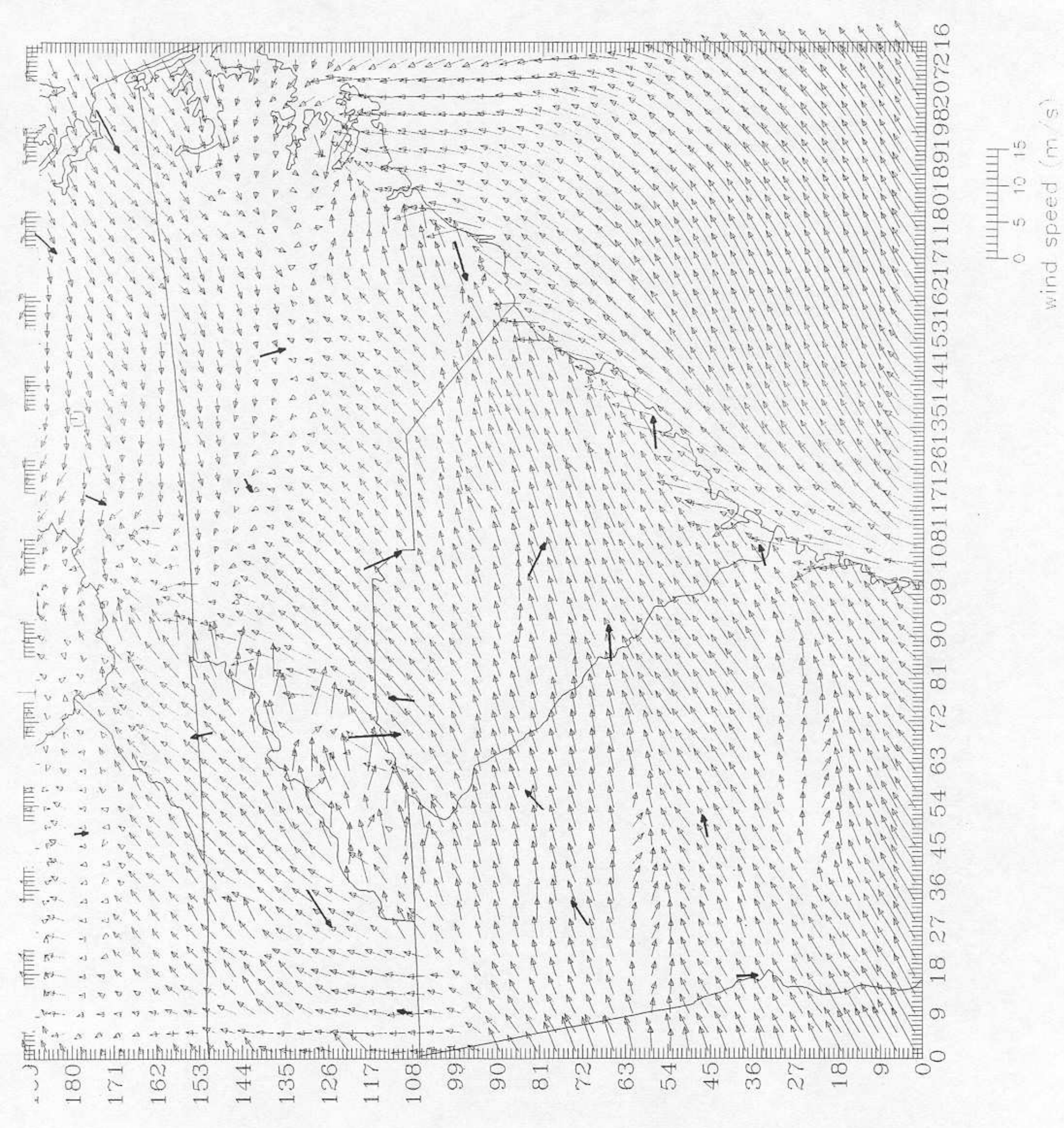

FIGURE 4-3(h). MM5 surface wind fields at 1300 EST on 23 May 1998 for the 4-km resolution SCDHEC grid.

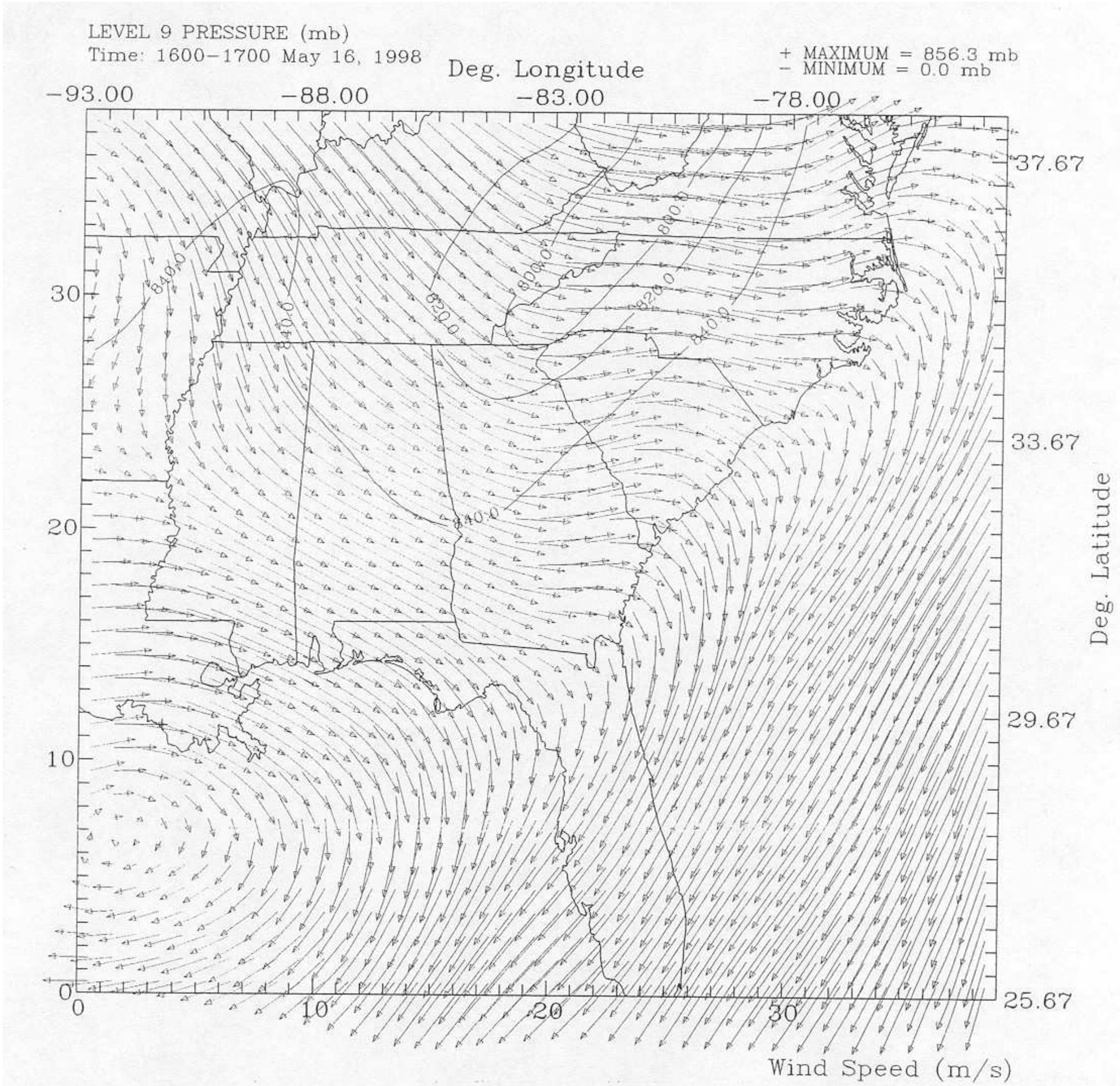

FIGURE 4-4a. UAM-V ready wind fields at 1500 m (Level 9) for 36 km SCDHEC domain (Grid 1).

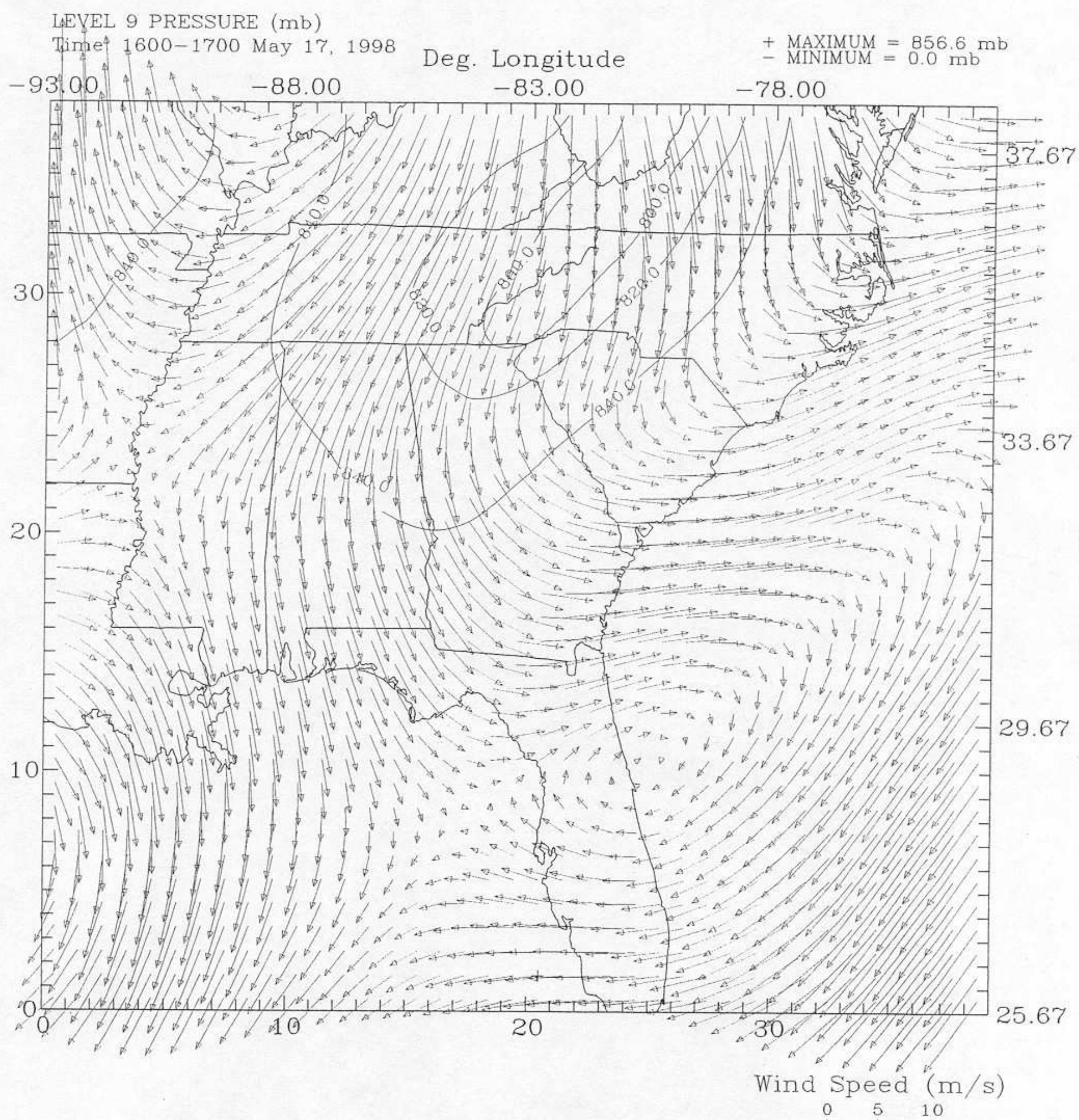

FIGURE 4-4b. UAM-V ready wind fields at 1500 m (Level 9) for 36 km SCDHEC domain (Grid 1).

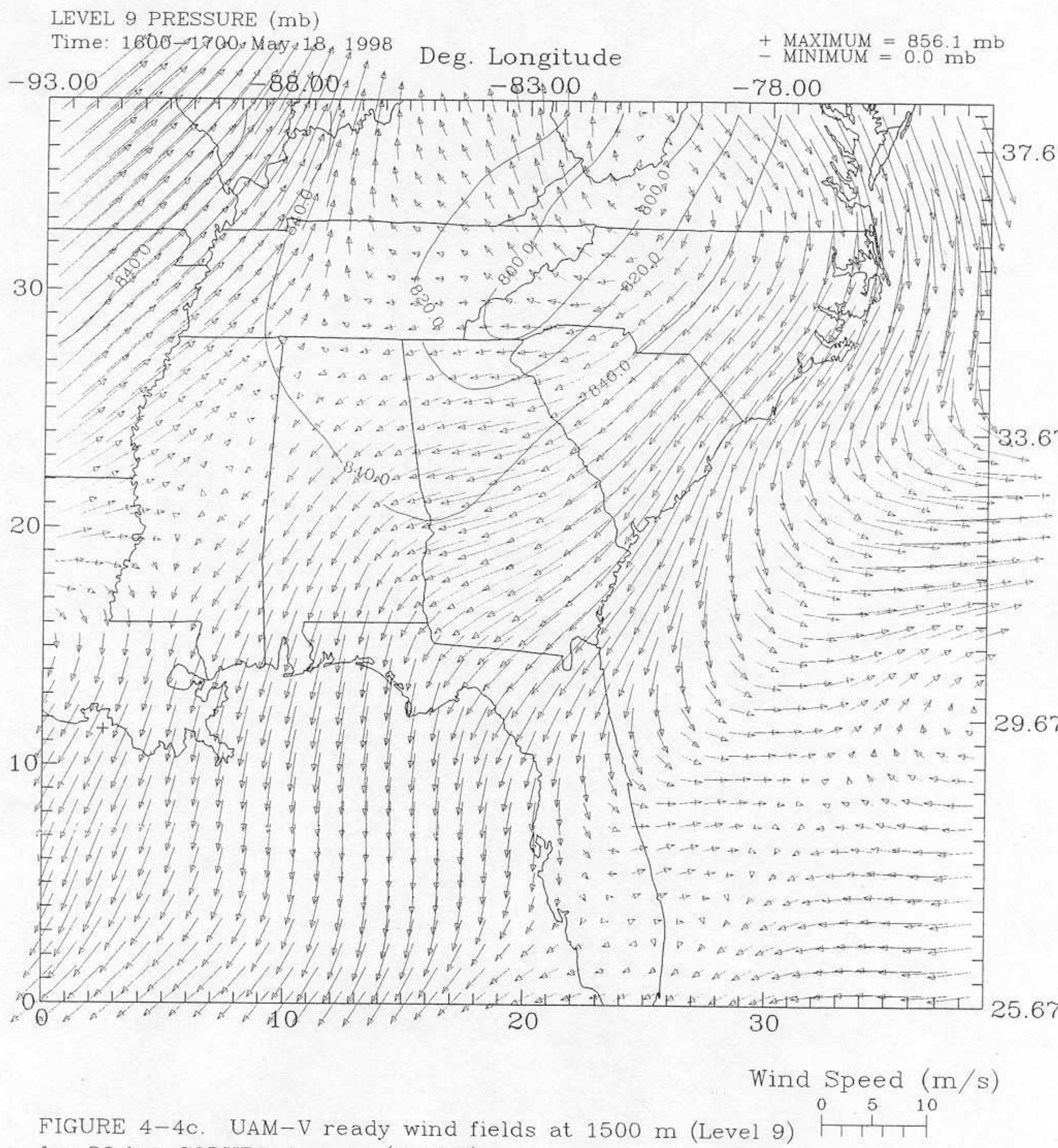

FIGURE 4−4c. UAM−V ready wind fields at 1500 m (Level 9) for 36 km SCDHEC domain (Grid 1).

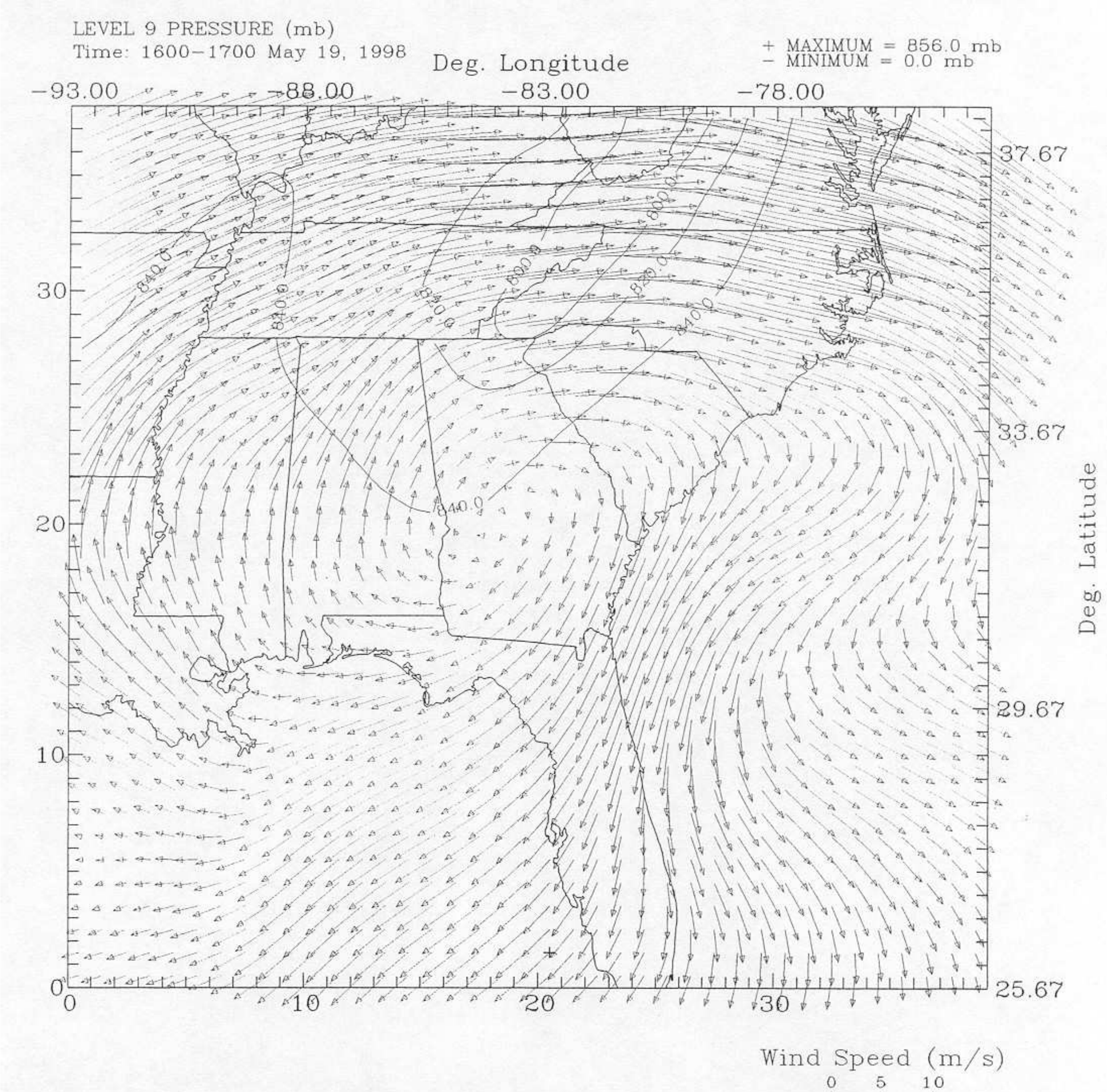

FIGURE 4-4d. UAM-V ready wind fields at 1500 m (Level 9) for 36 km SCDHEC domain (Grid 1).

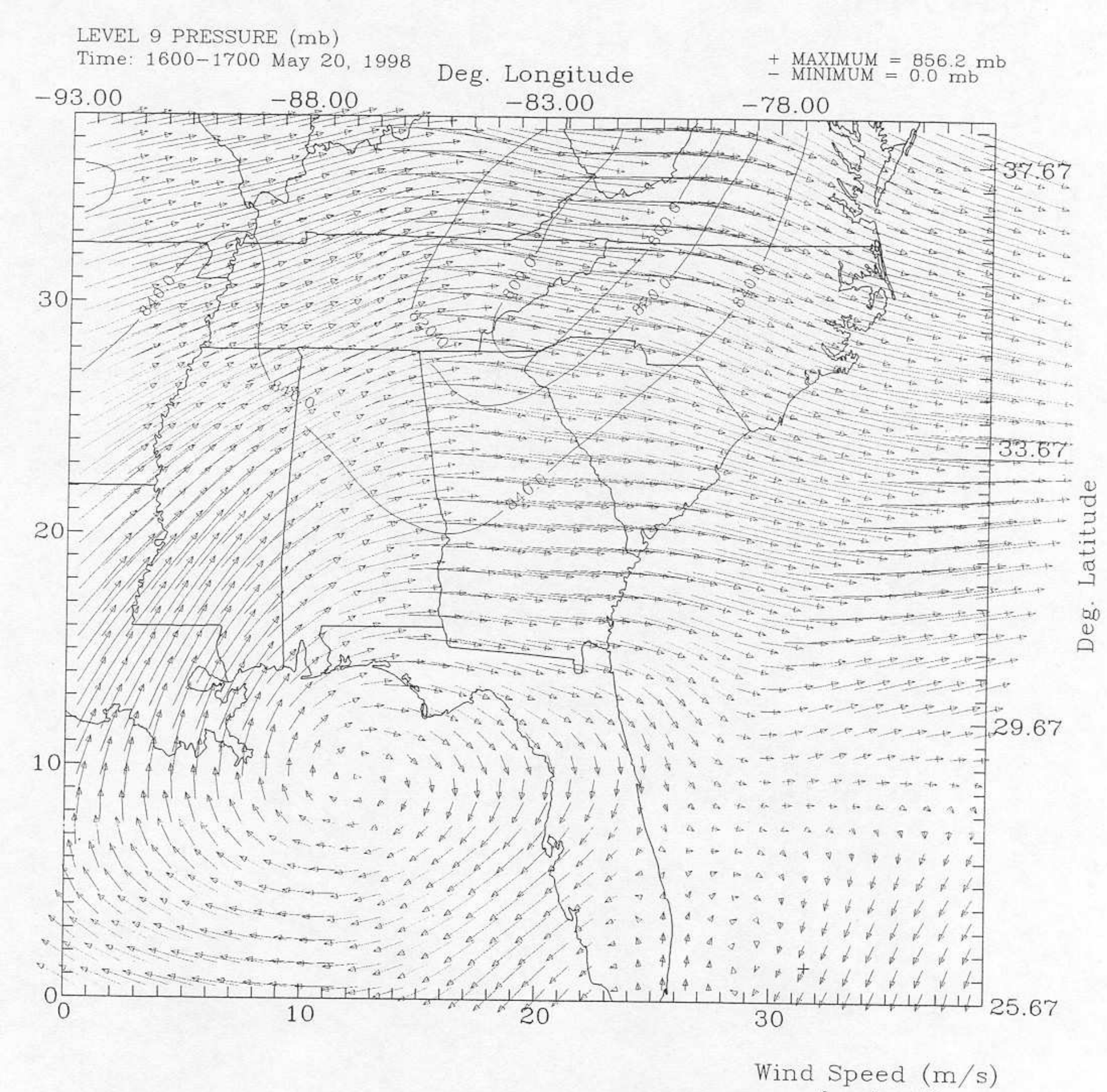

FIGURE 4-4e. UAM-V ready wind fields at 1500 m (Level 9) for 36 km SCDHEC domain (Grid 1).

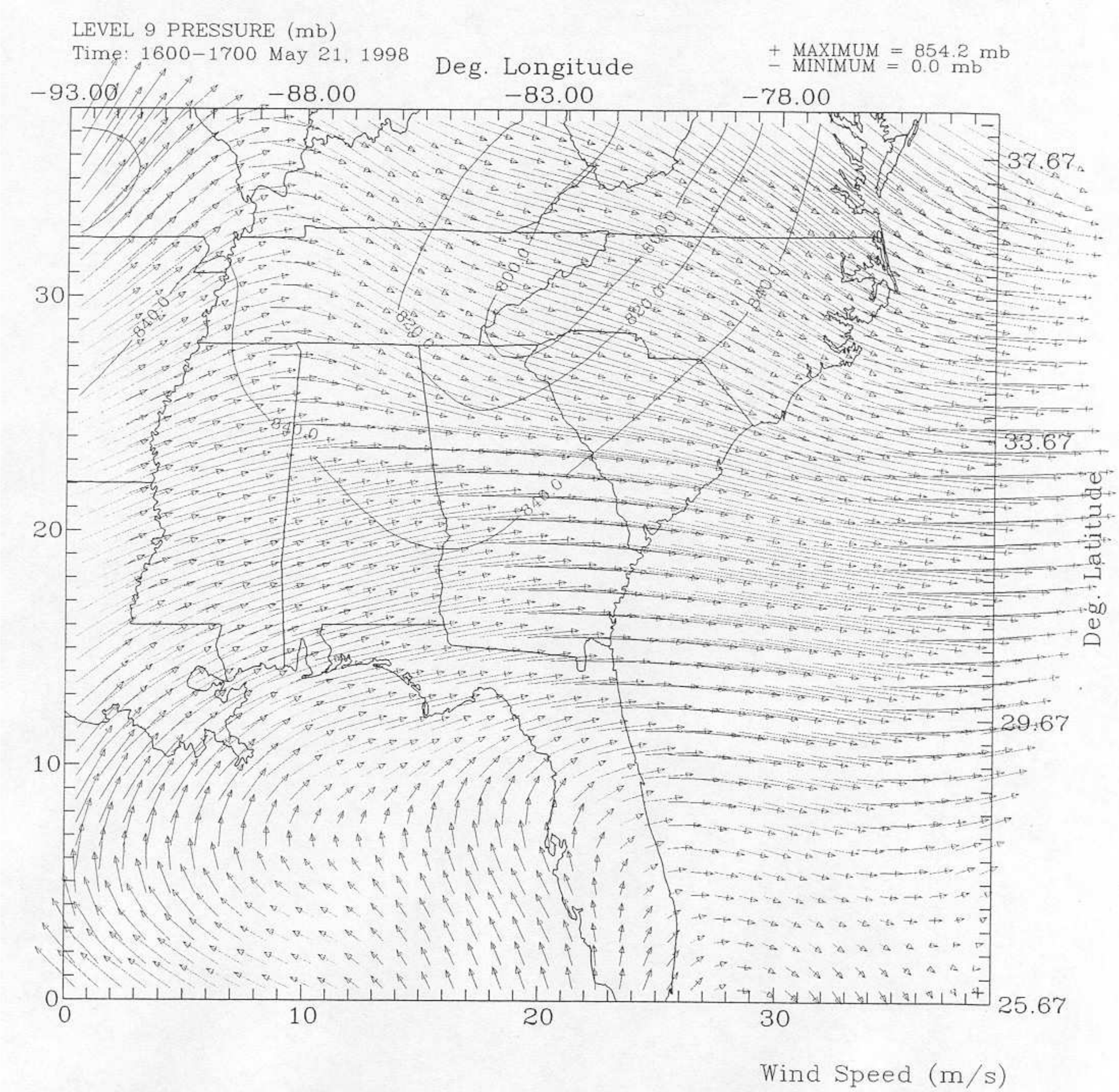

FIGURE 4−4f. UAM−V ready wind fields at 1500 m (Level 9) for 36 km SCDHEC domain (Grid 1).

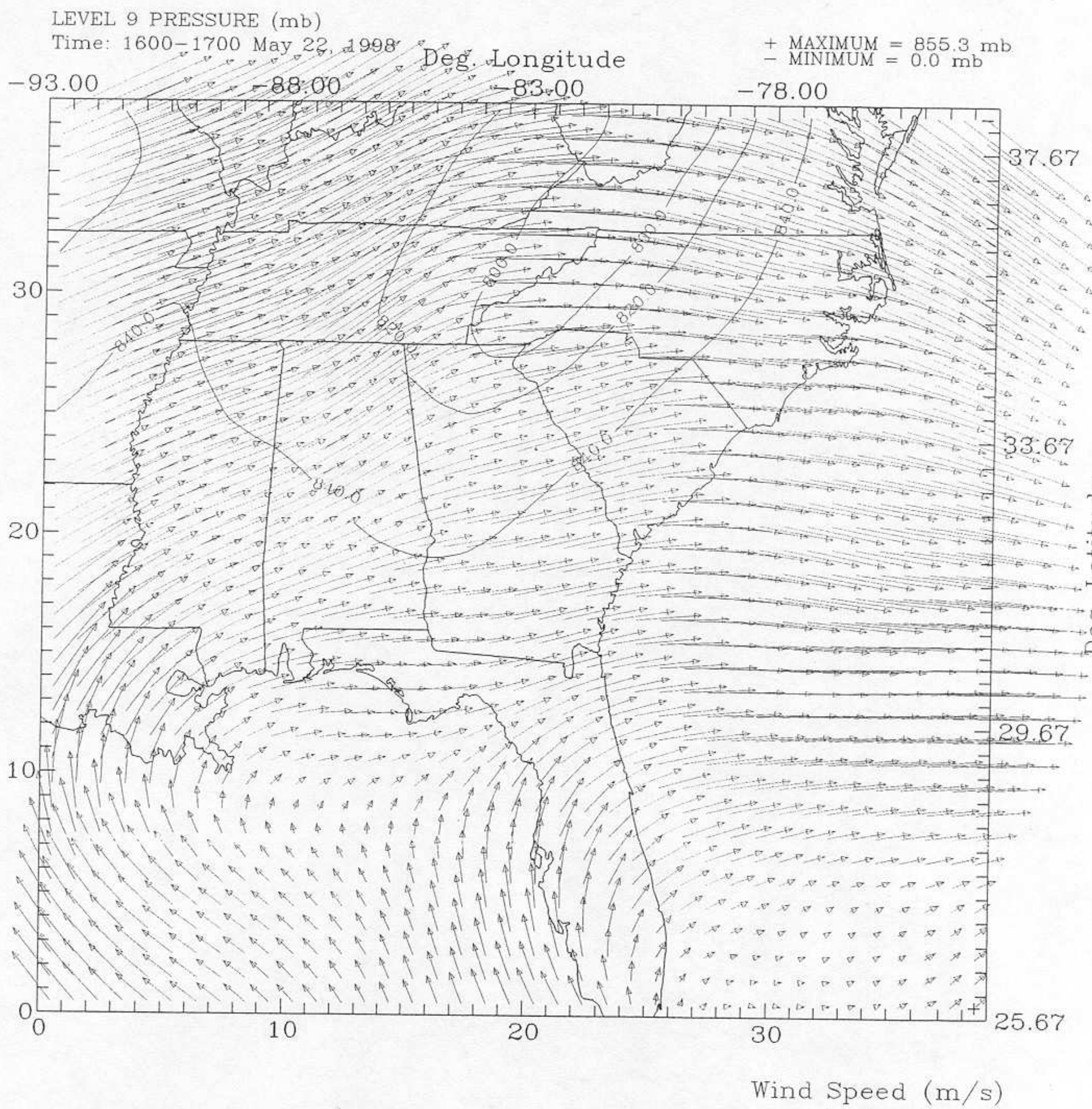

FIGURE 4-4g. UAM-V ready wind fields at 1500 m (Level 9) for 36 km SCDHEC domain (Grid 1).

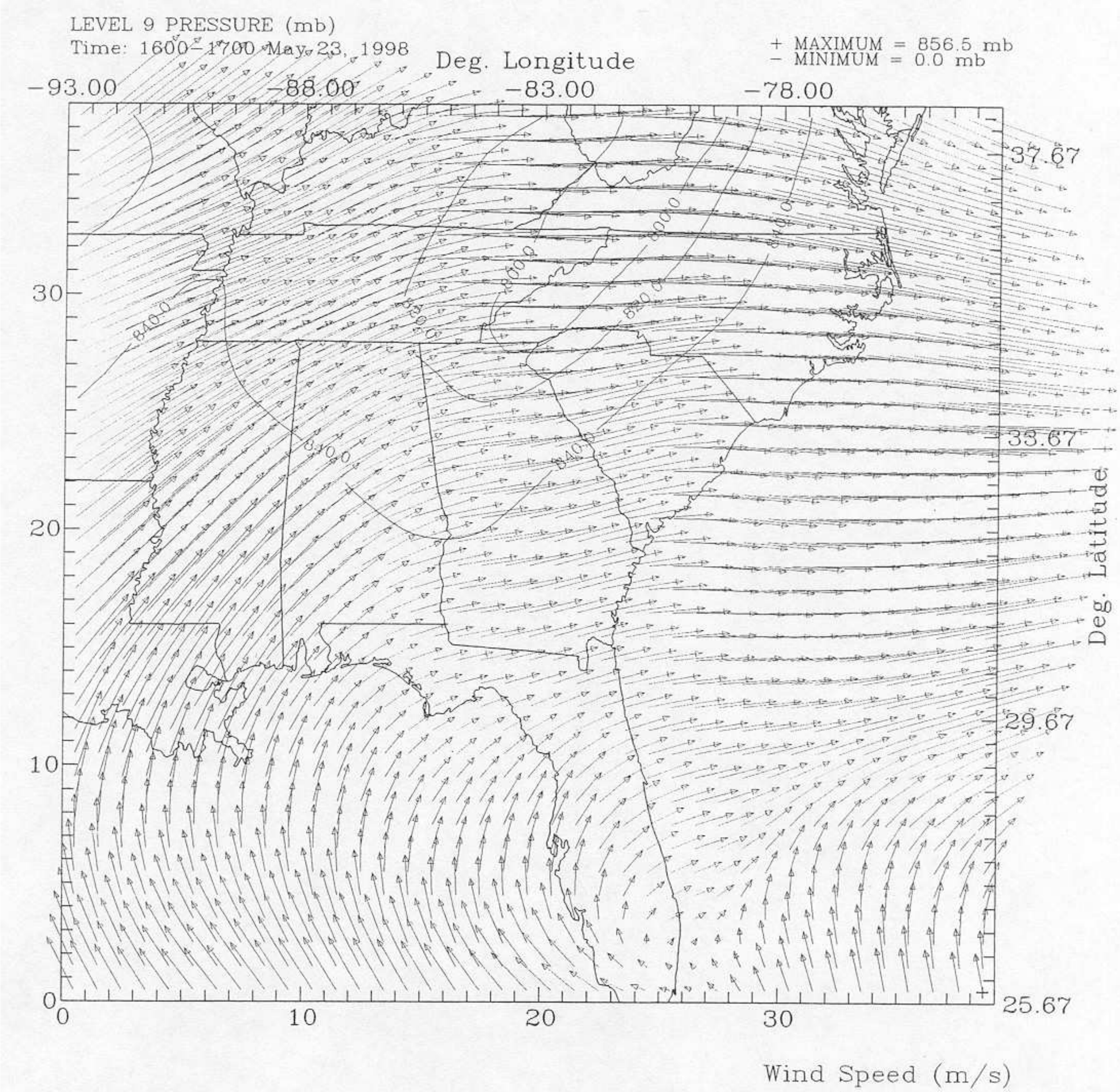

FIGURE 4-4h. UAM-V ready wind fields at 1500 m (Level 9) for 36 km SCDHEC domain (Grid 1).

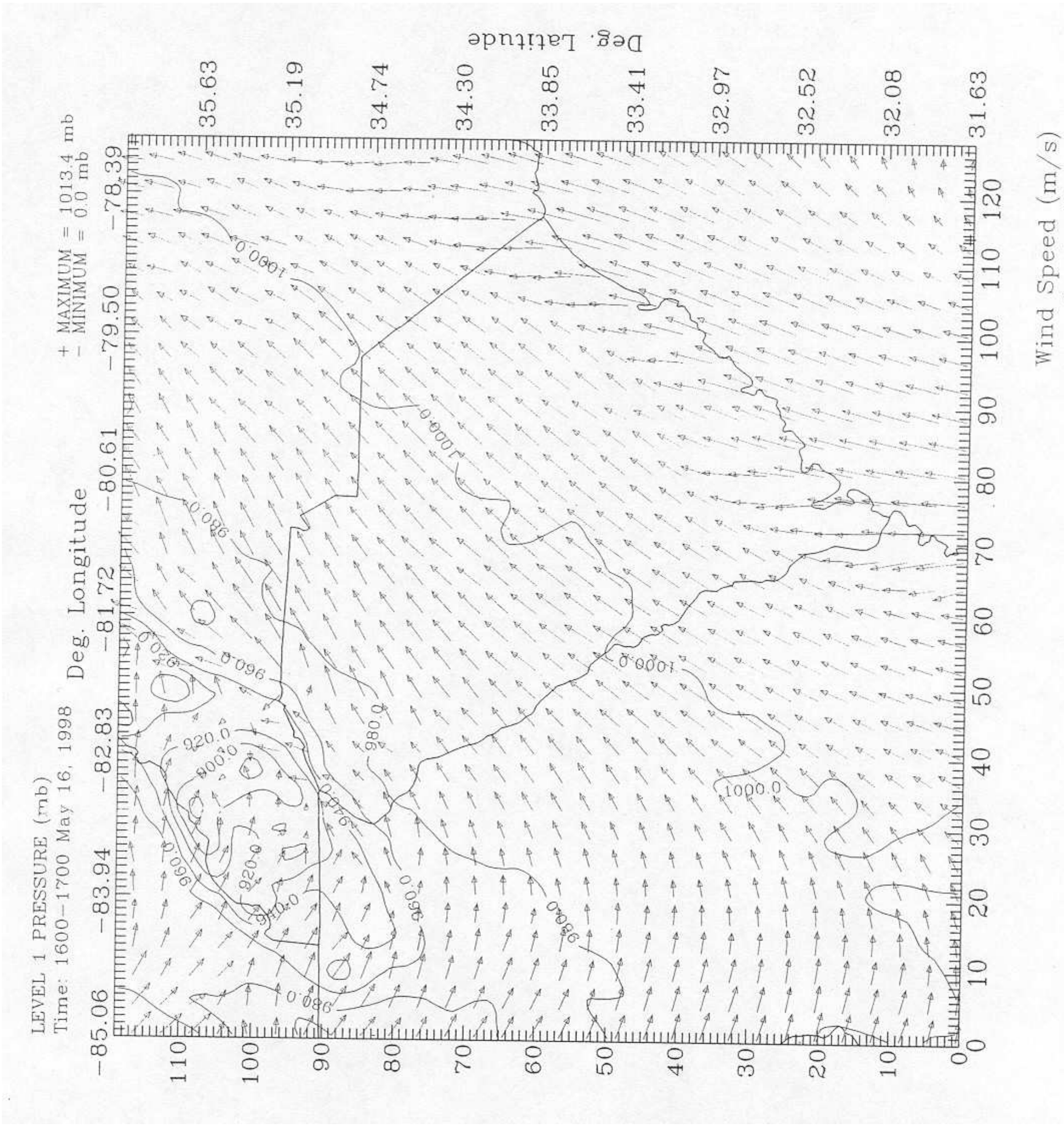

FIGURE 4-5a. UAM-V ready wind fields at 25 m (Level 1) for 4 km SCDHEC domain (Grid 3).

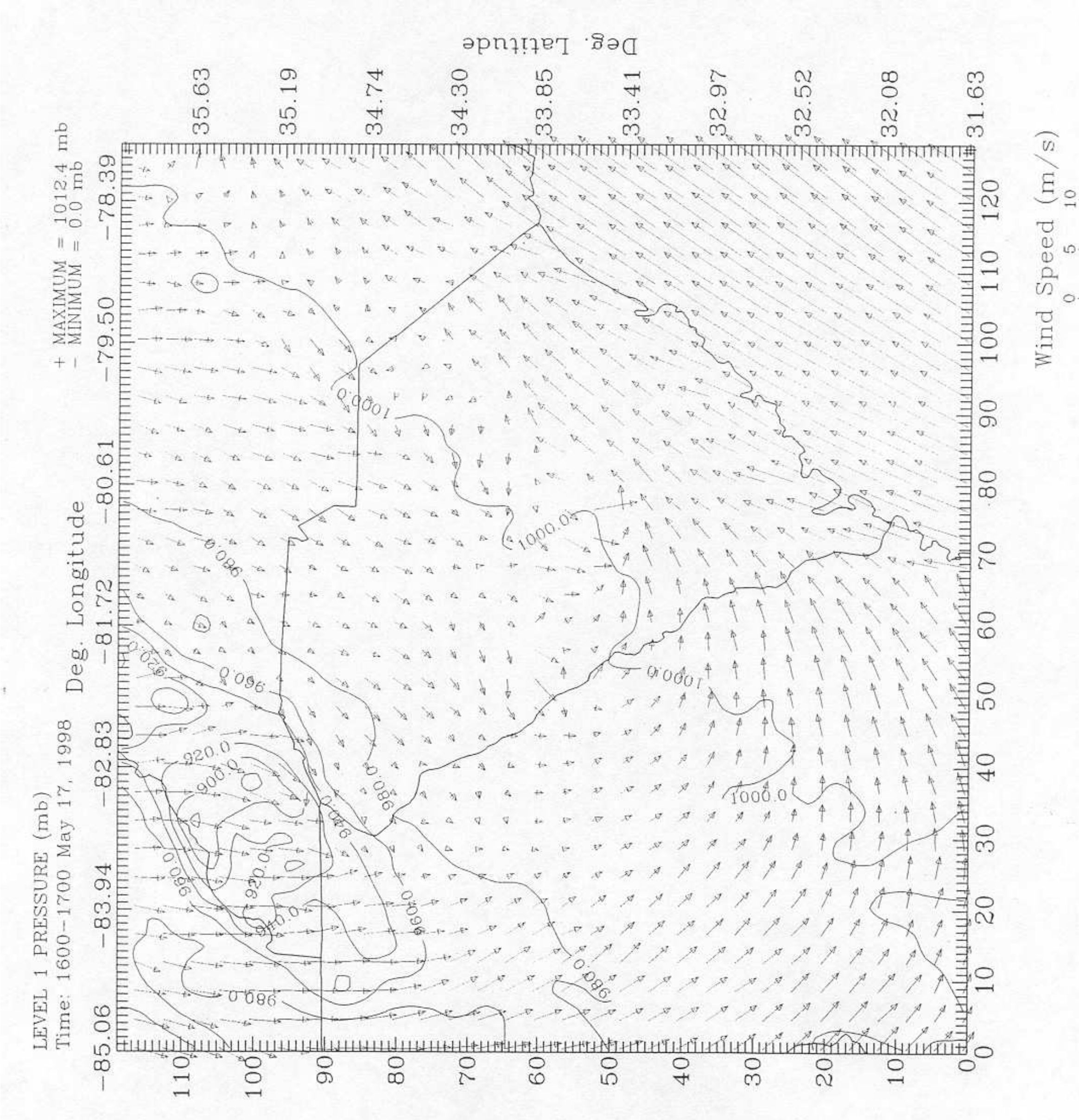

FIGURE 4-5b. UAM-V ready wind fields at 25 m (Level 1) for 4 km SCDHEC domain (Grid 3).

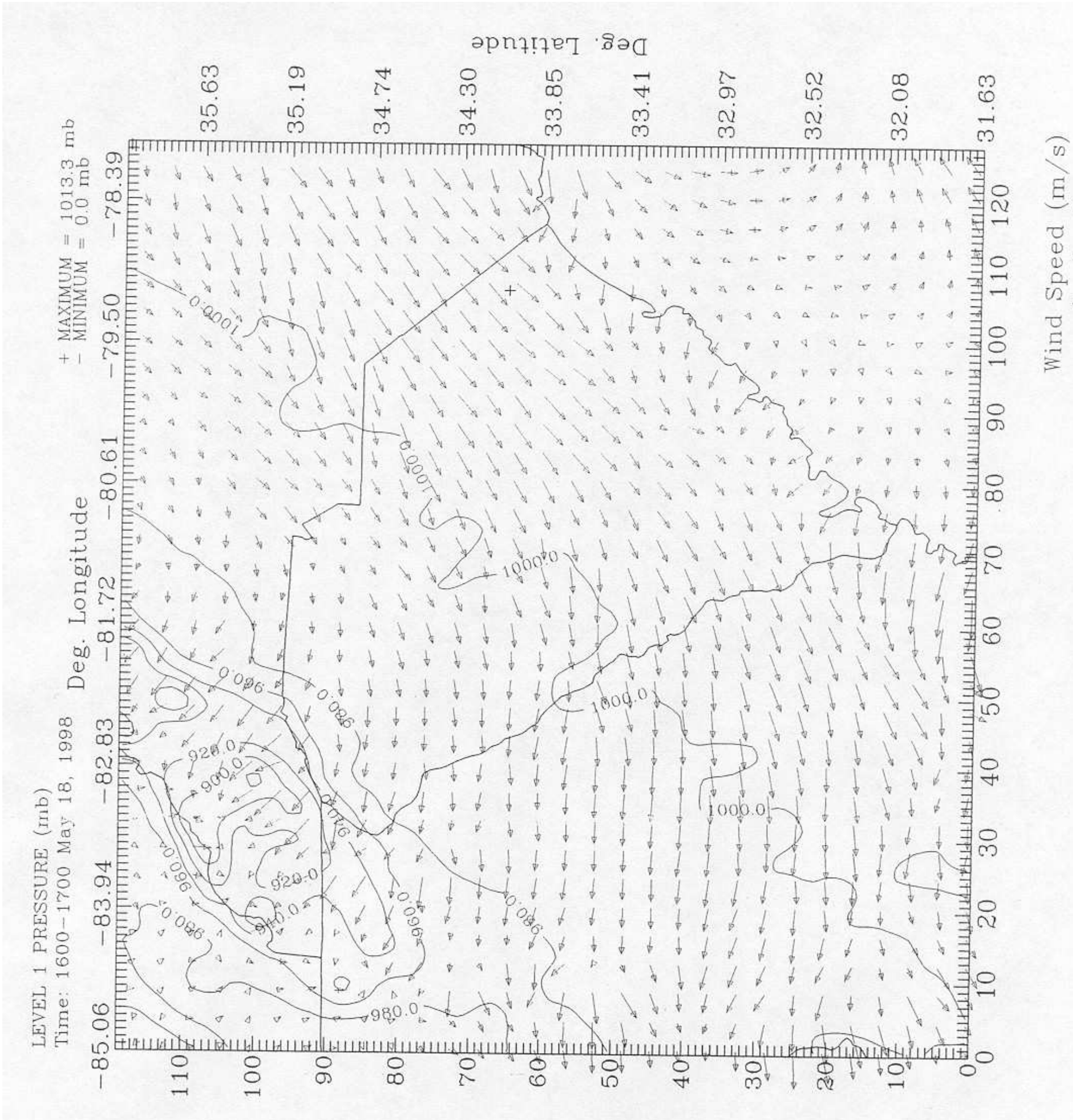

FIGURE 4-5c. UAM-V ready wind fields at 25 m (Level 1) for 4 km SCDHEC domain (Grid 3).

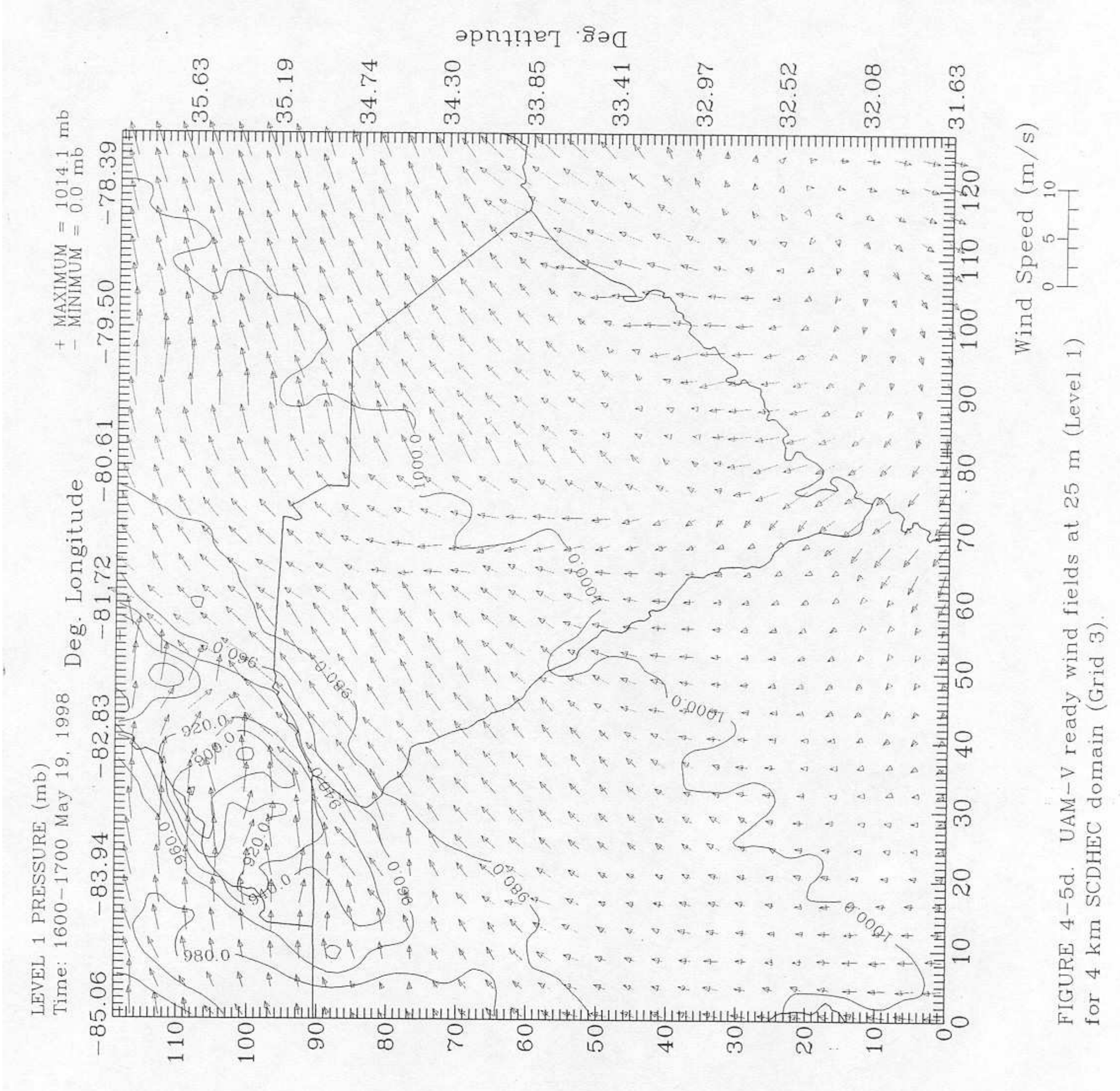

FIGURE 4-5d. UAM-V ready wind fields at 25 m (Level 1) for 4 km SCDHEC domain (Grid 3).

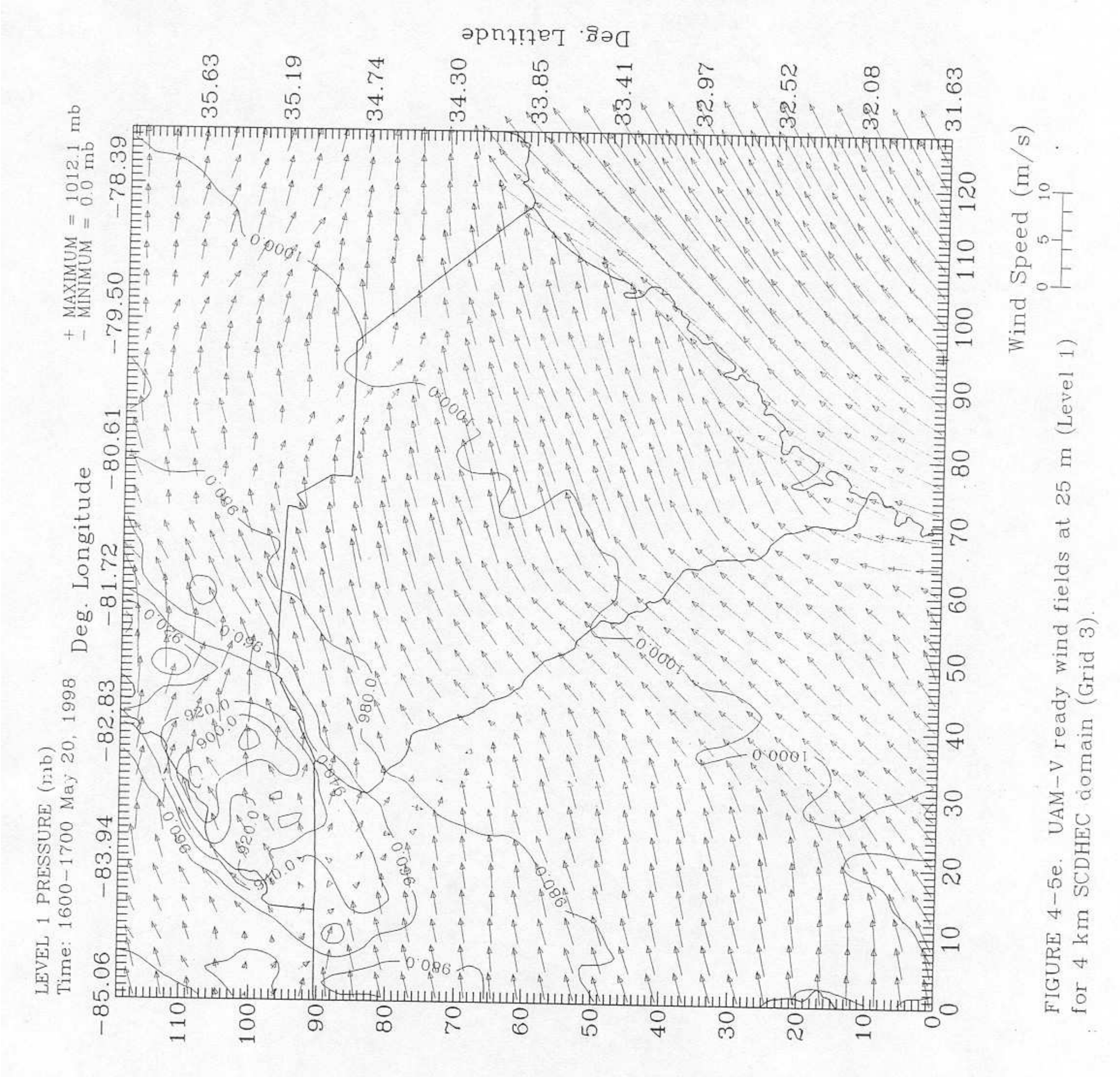

FIGURE 4-5e. UAM-V ready wind fields at 25 m (Level 1) for 4 km SCDHEC domain (Grid 3).

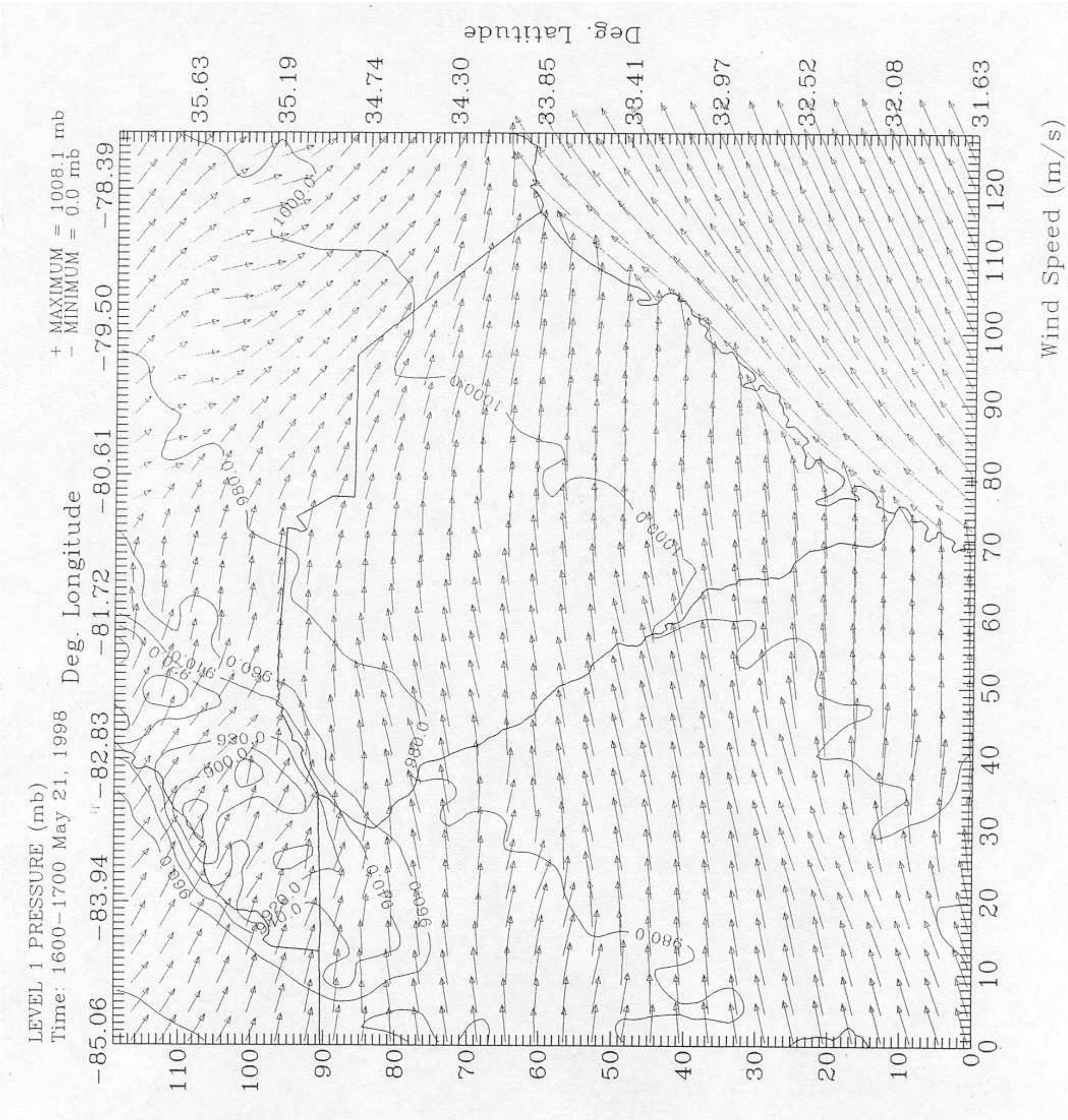

FIGURE 4-5f. UAM-V ready wind fields at 25 m (Level 1) for 4 km SCDHEC domain (Grid 3).

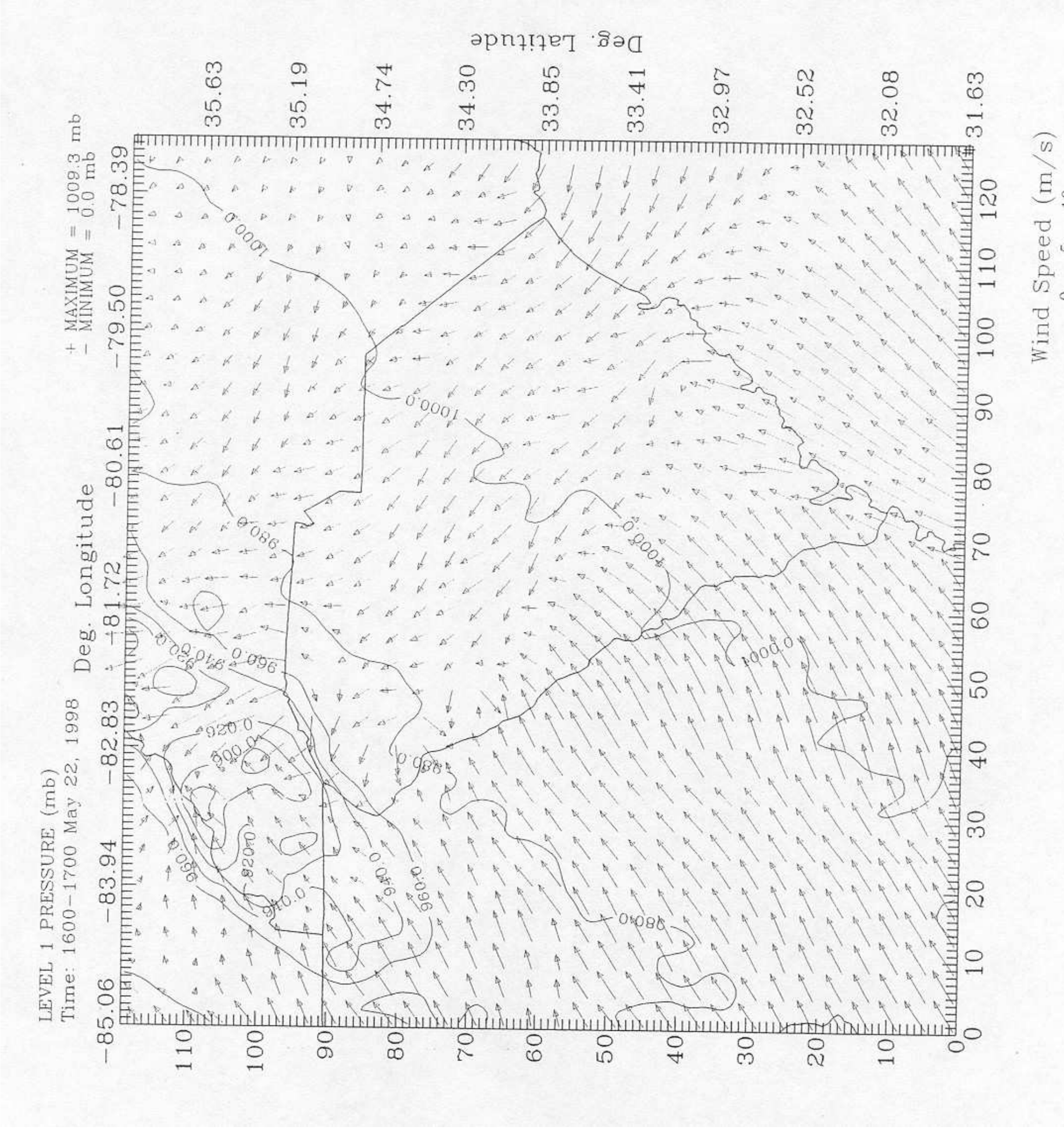

FIGURE 4-5g. UAM-V ready wind fields at 25 m (Level 1) for 4 km SCDHEC domain (Grid 3).

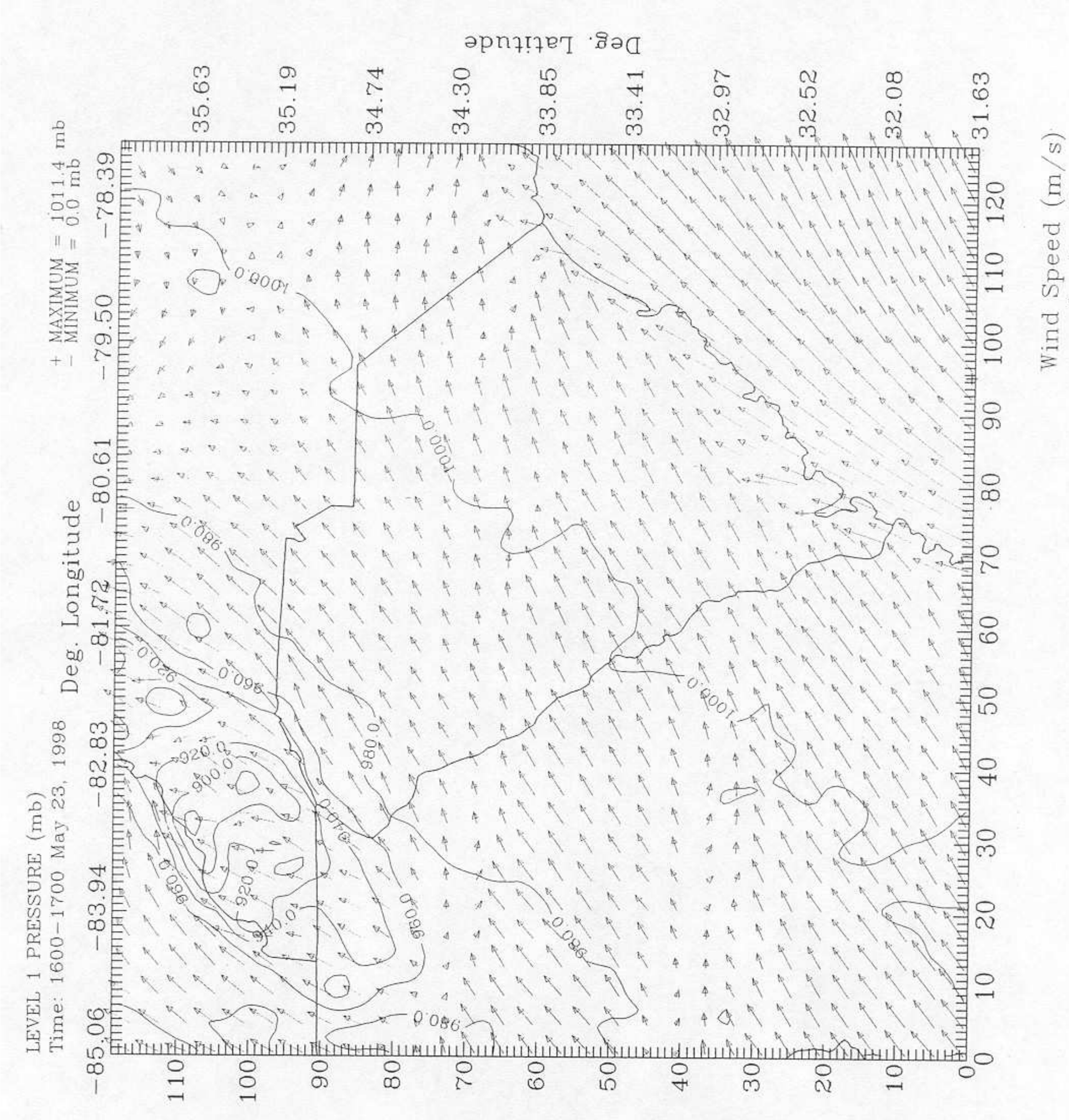

FIGURE 4-5h. UAM-V ready wind fields at 25 m (Level 1) for 4 km SCDHEC domain (Grid 3).

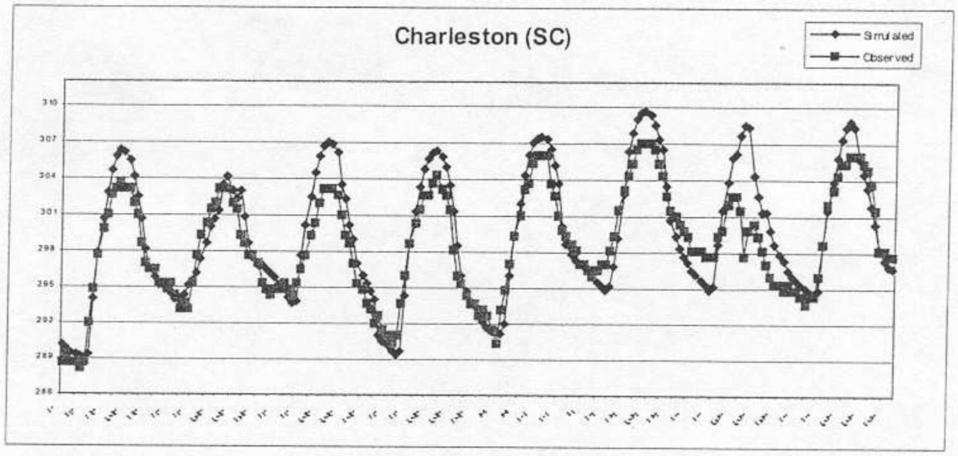

FIGURE 4-6a
Simulated and observed temperatures at the Charleston monitoring site, 16 – 23 May 1998.

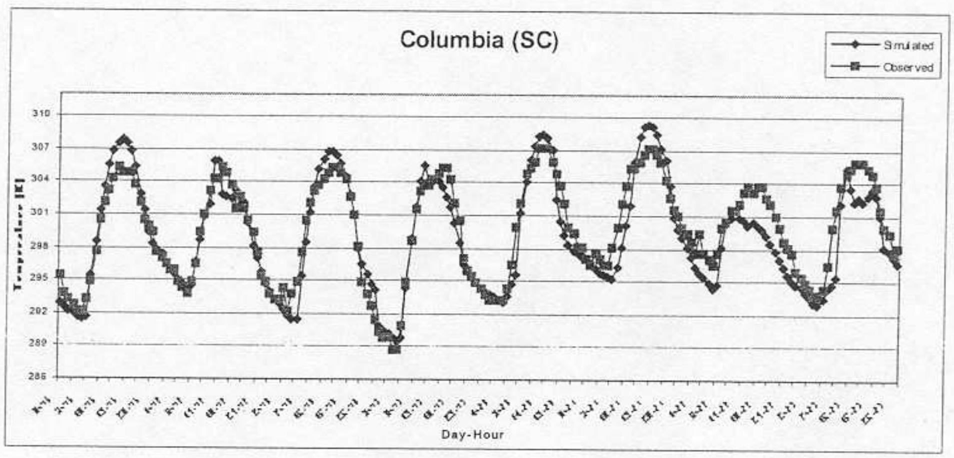

FIGURE 4-6b
Simulated and observed temperatures at the Columbia monitoring site, 16 – 23 May 1998.

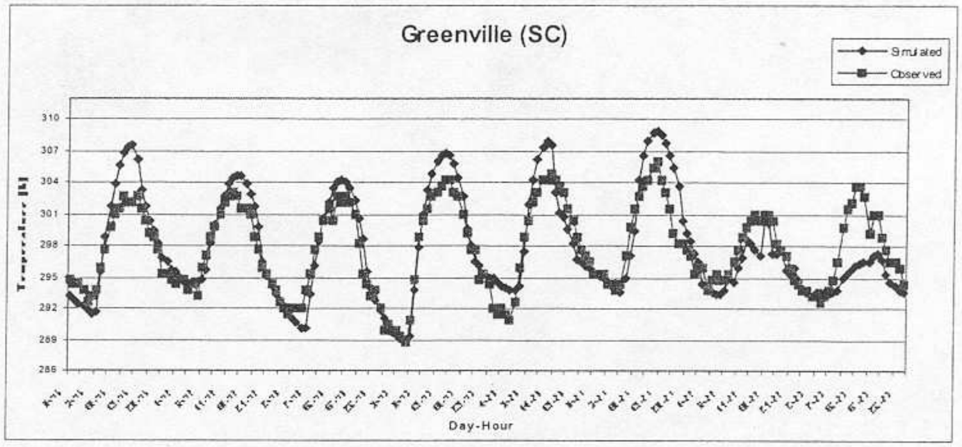

FIGURE 4-6c
Simulated and observed temperatures at the Greenville monitoring site, 16 – 23 May 1998.

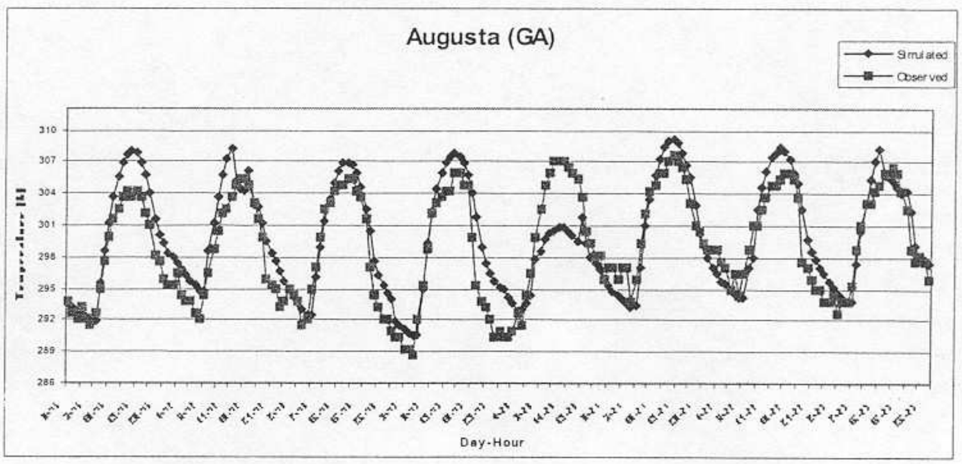

FIGURE 4-6d
Simulated and observed temperatures at the Augusta monitoring site, 16 – 23 May 1998.

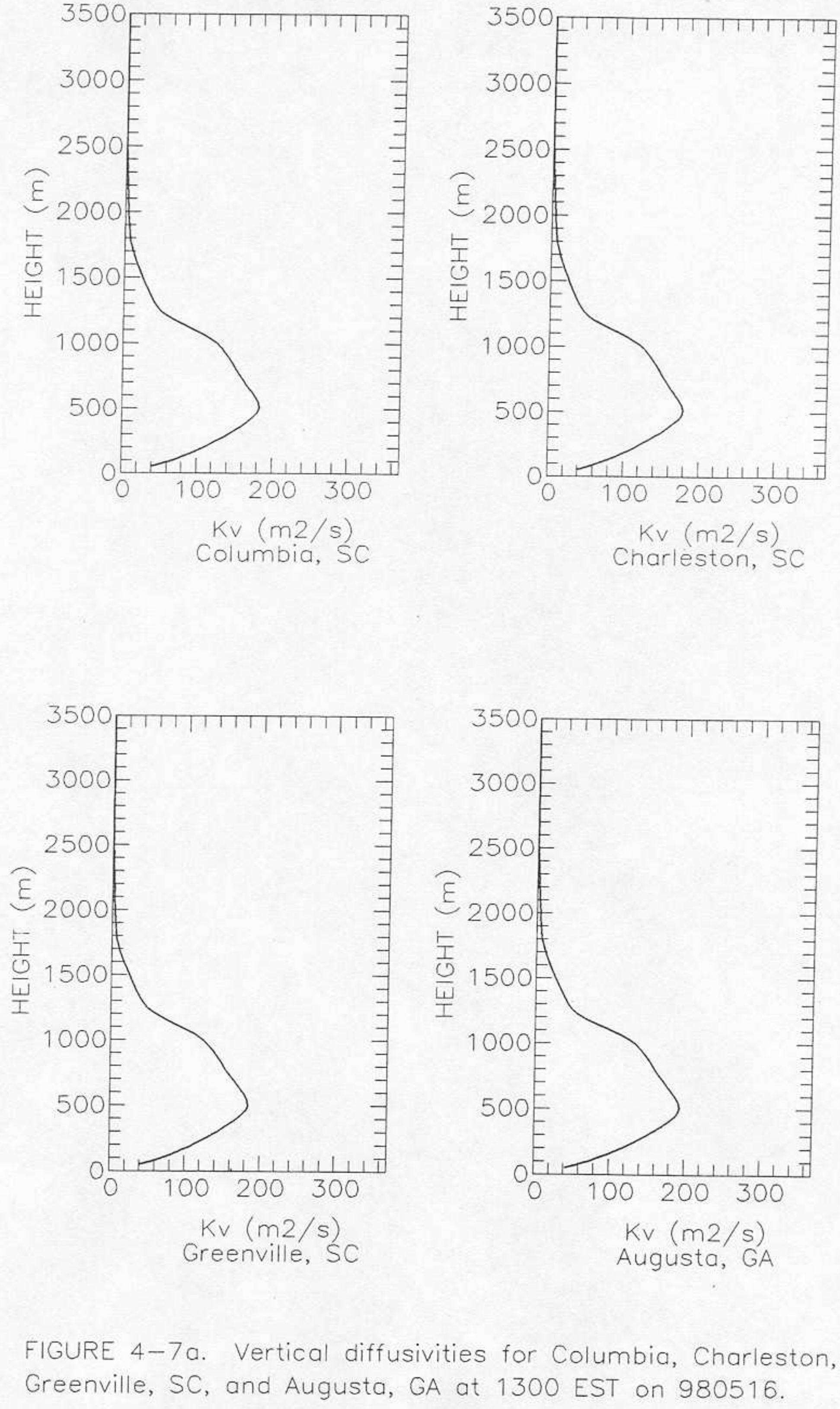

FIGURE 4–7a. Vertical diffusivities for Columbia, Charleston, and Greenville, SC, and Augusta, GA at 1300 EST on 980516.

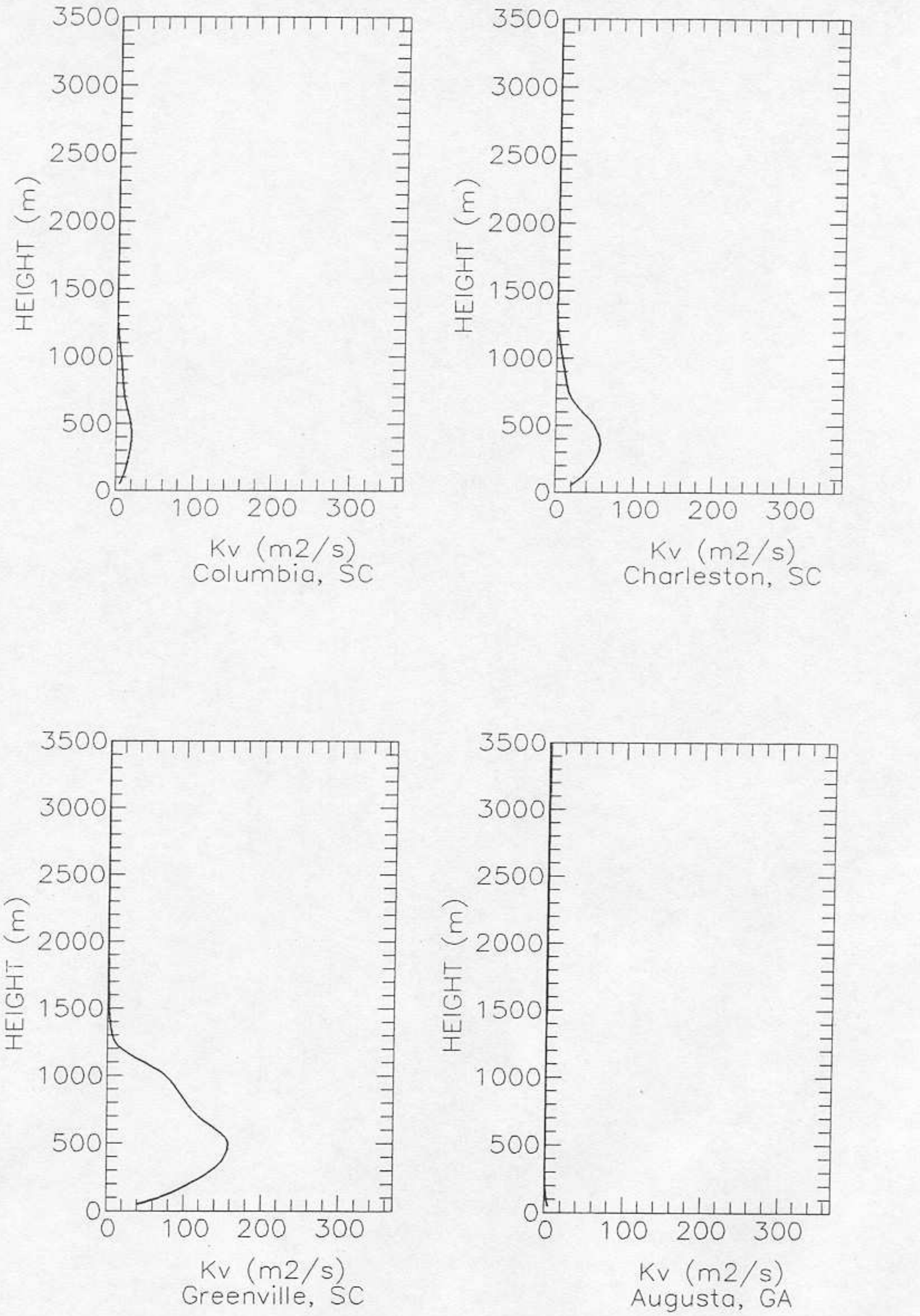

FIGURE 4-7b. Vertical diffusivities for Columbia, Charleston, and Greenville, SC, and Augusta, GA at 1300 EST on 980517.

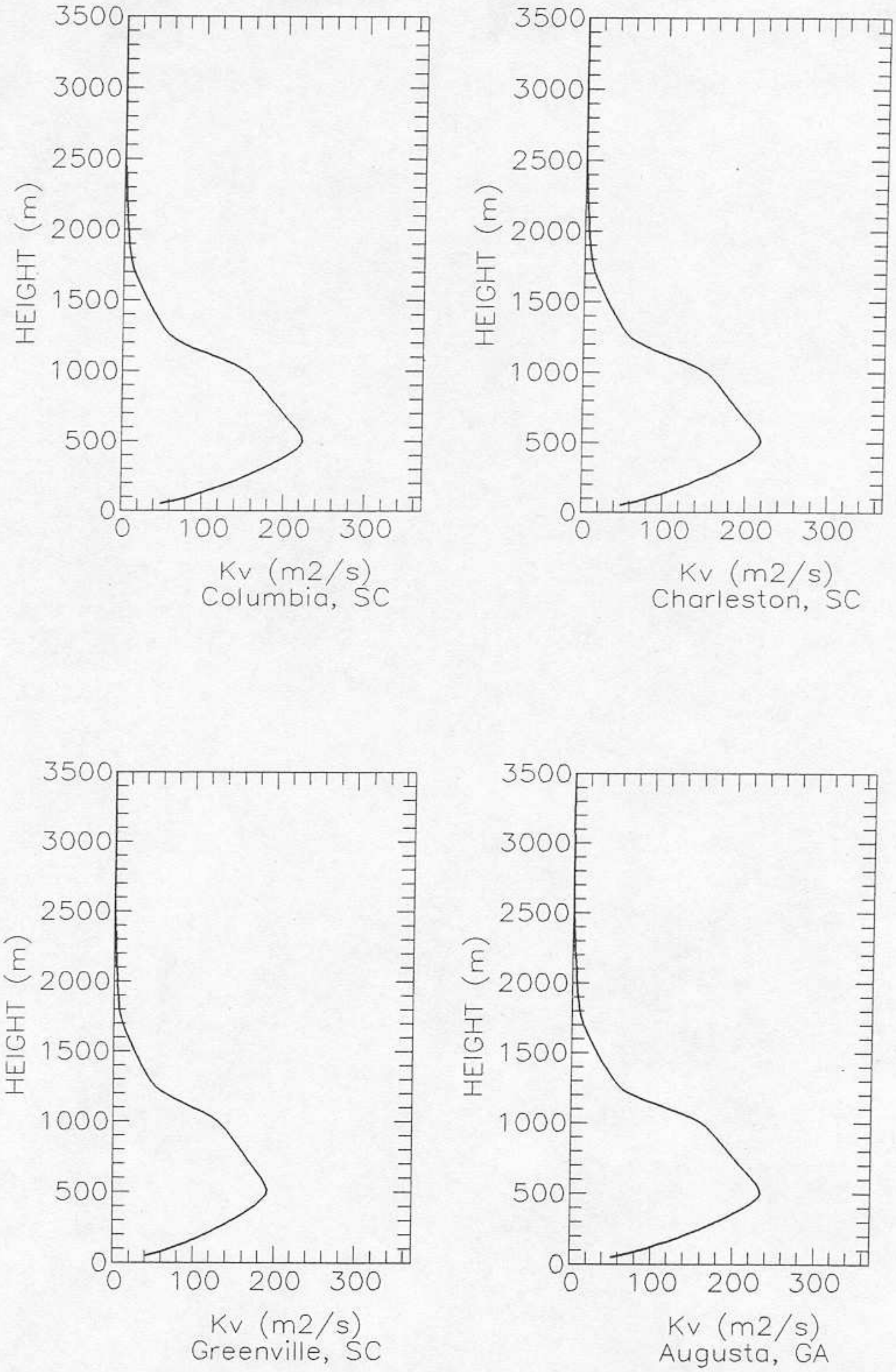

FIGURE 4–7c. Vertical diffusivities for Columbia, Charleston, and Greenville, SC, and Augusta, GA at 1300 EST on 980518.

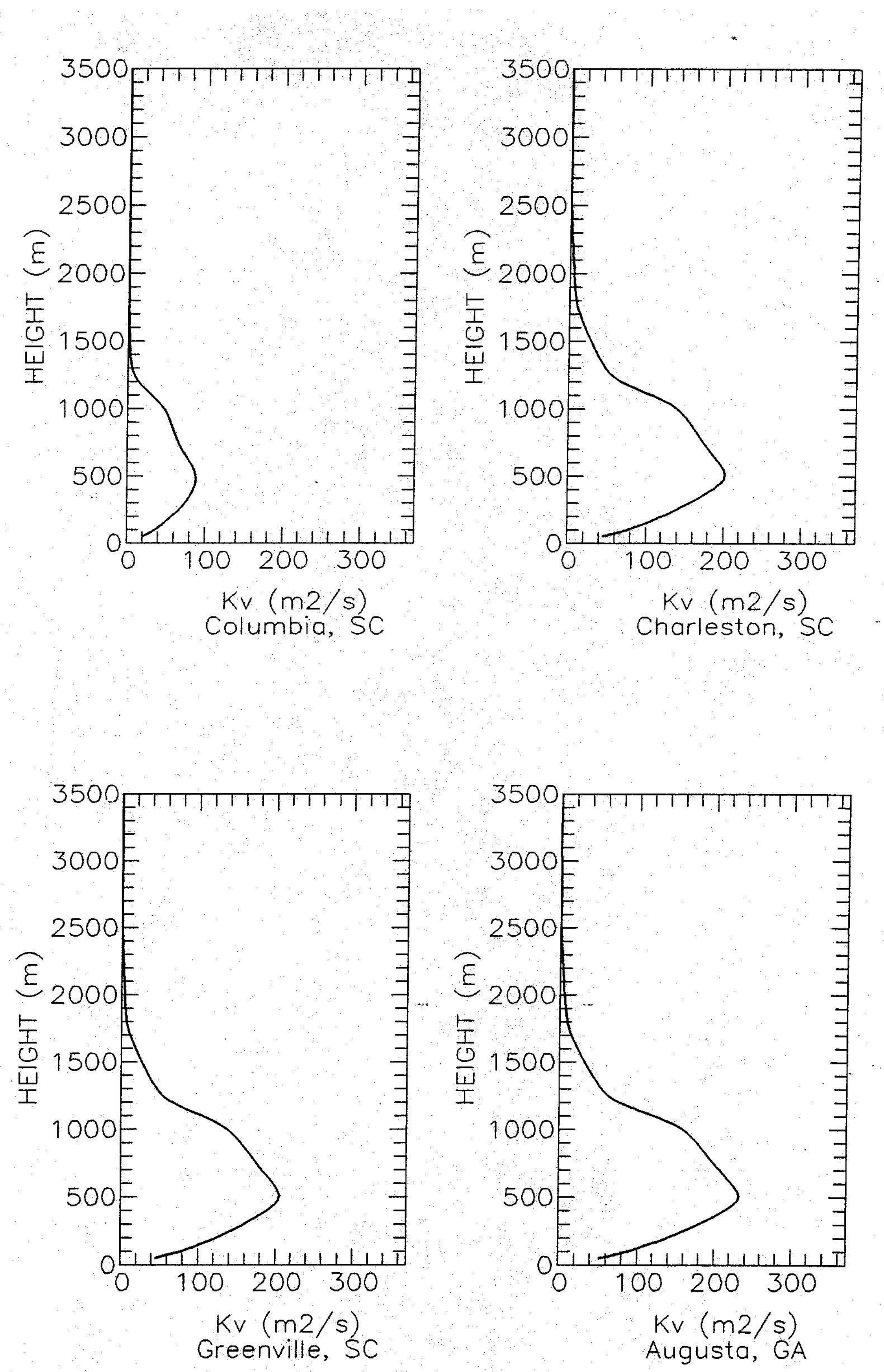

FIGURE 4–7d. Vertical diffusivities for Columbia, Charleston, and Greenville, SC, and Augusta, GA at 1300 EST on 980519.

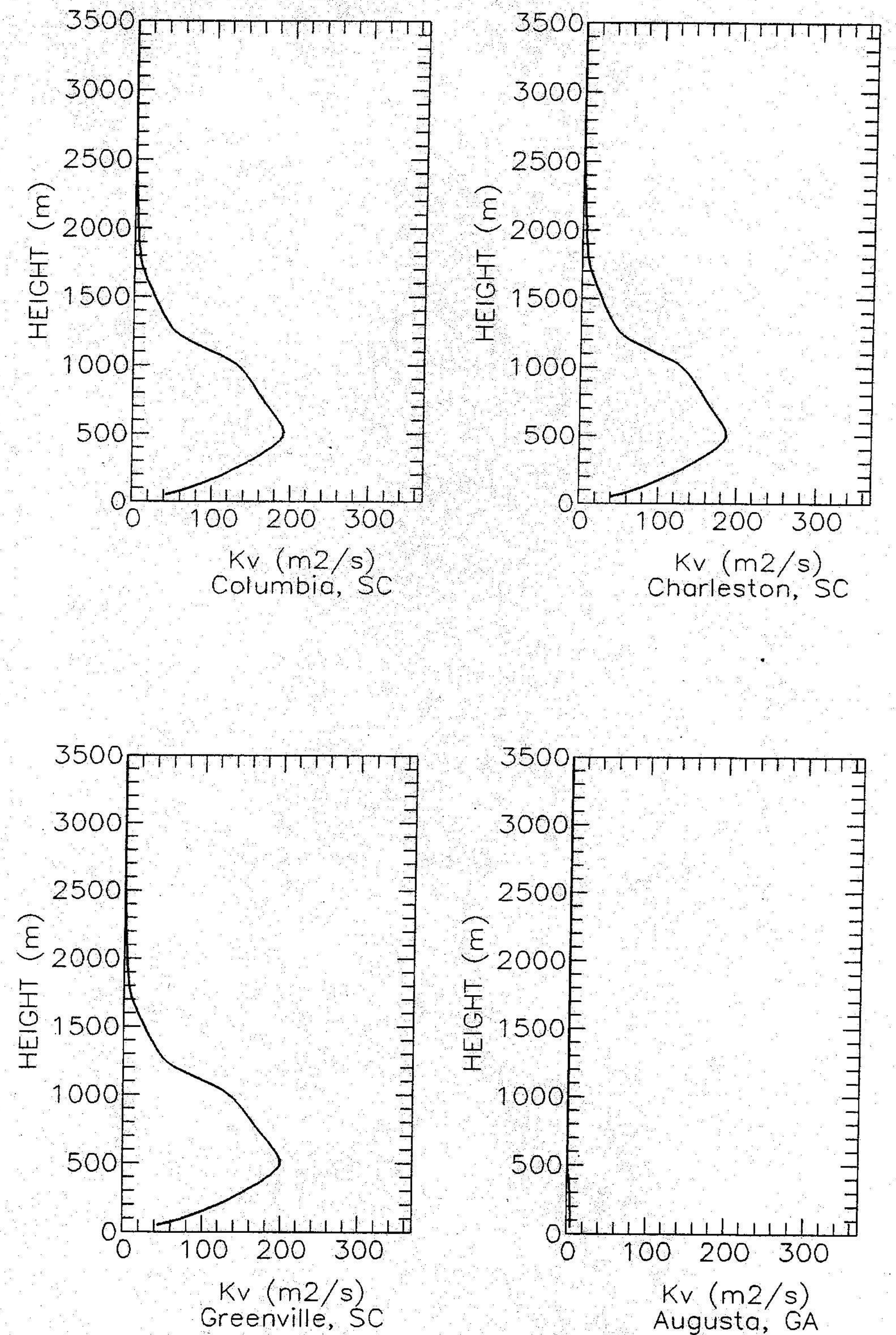

FIGURE 4–7e. Vertical diffusivities for Columbia, Charleston, and Greenville, SC, and Augusta, GA at 1300 EST on 980520.

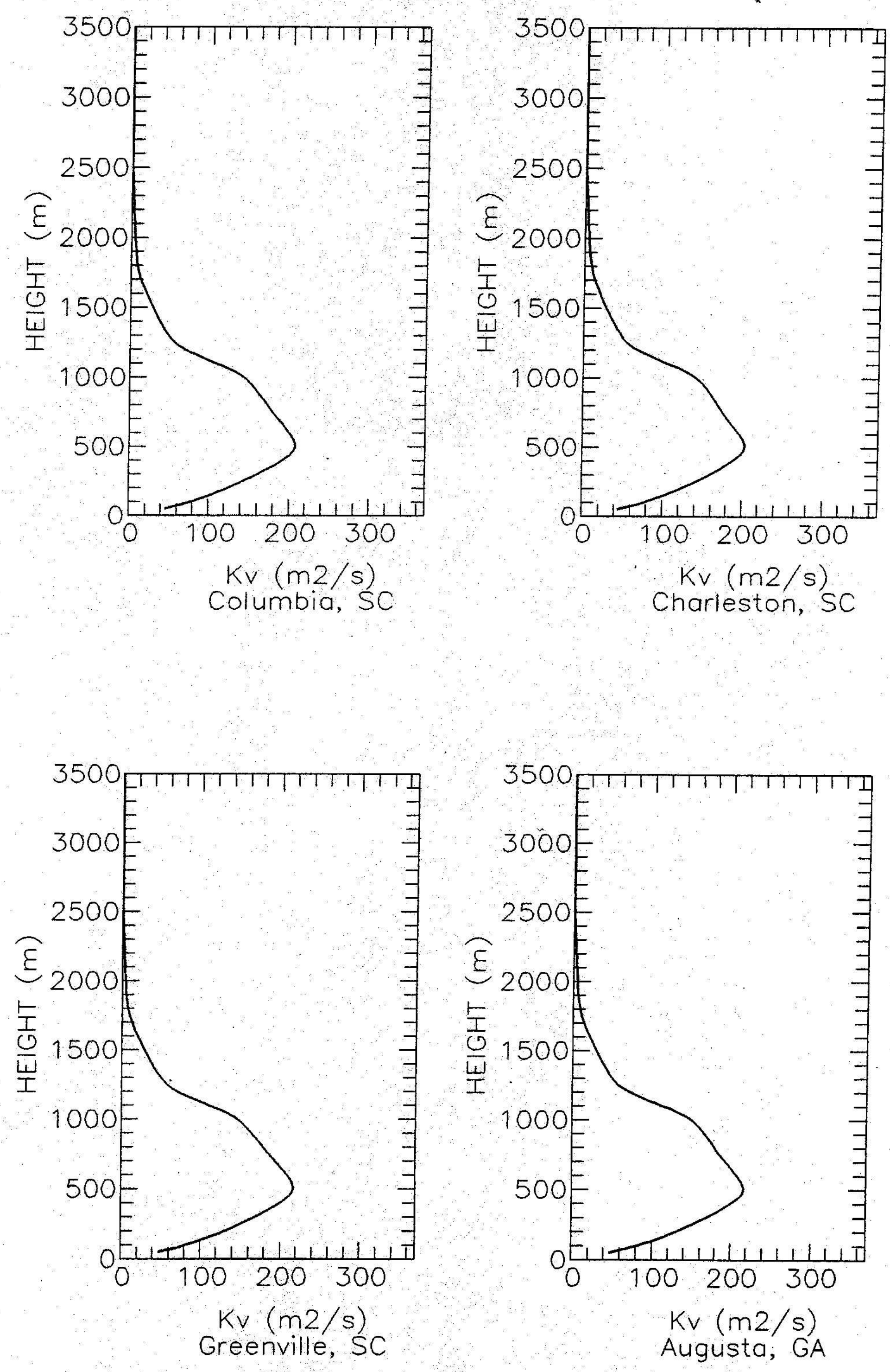

FIGURE 4-7f. Vertical diffusivities for Columbia, Charleston, and Greenville, SC, and Augusta, GA at 1300 EST on 980521.

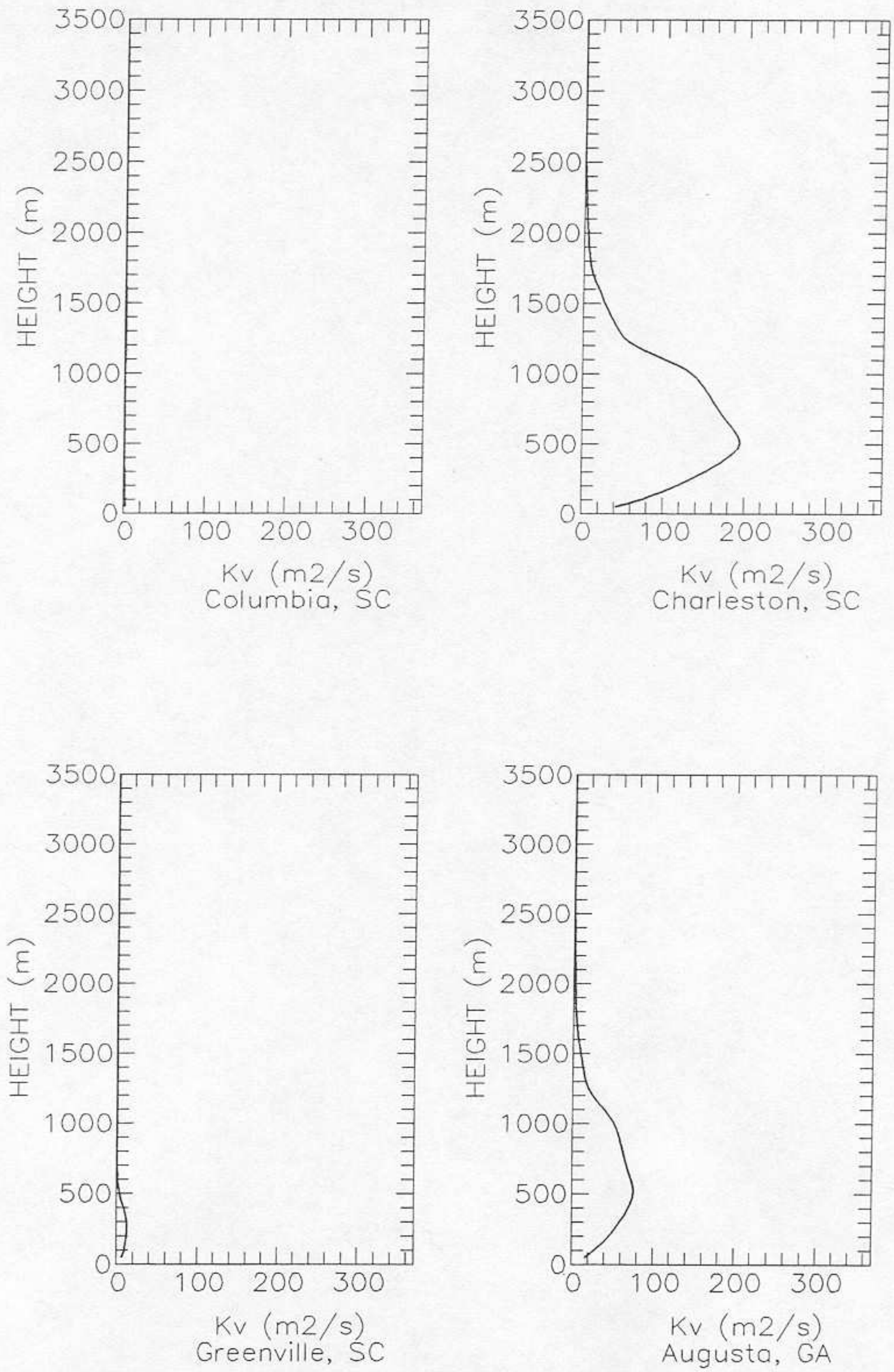

FIGURE 4–7g. Vertical diffusivities for Columbia, Charleston, and Greenville, SC, and Augusta, GA at 1300 EST on 980522.

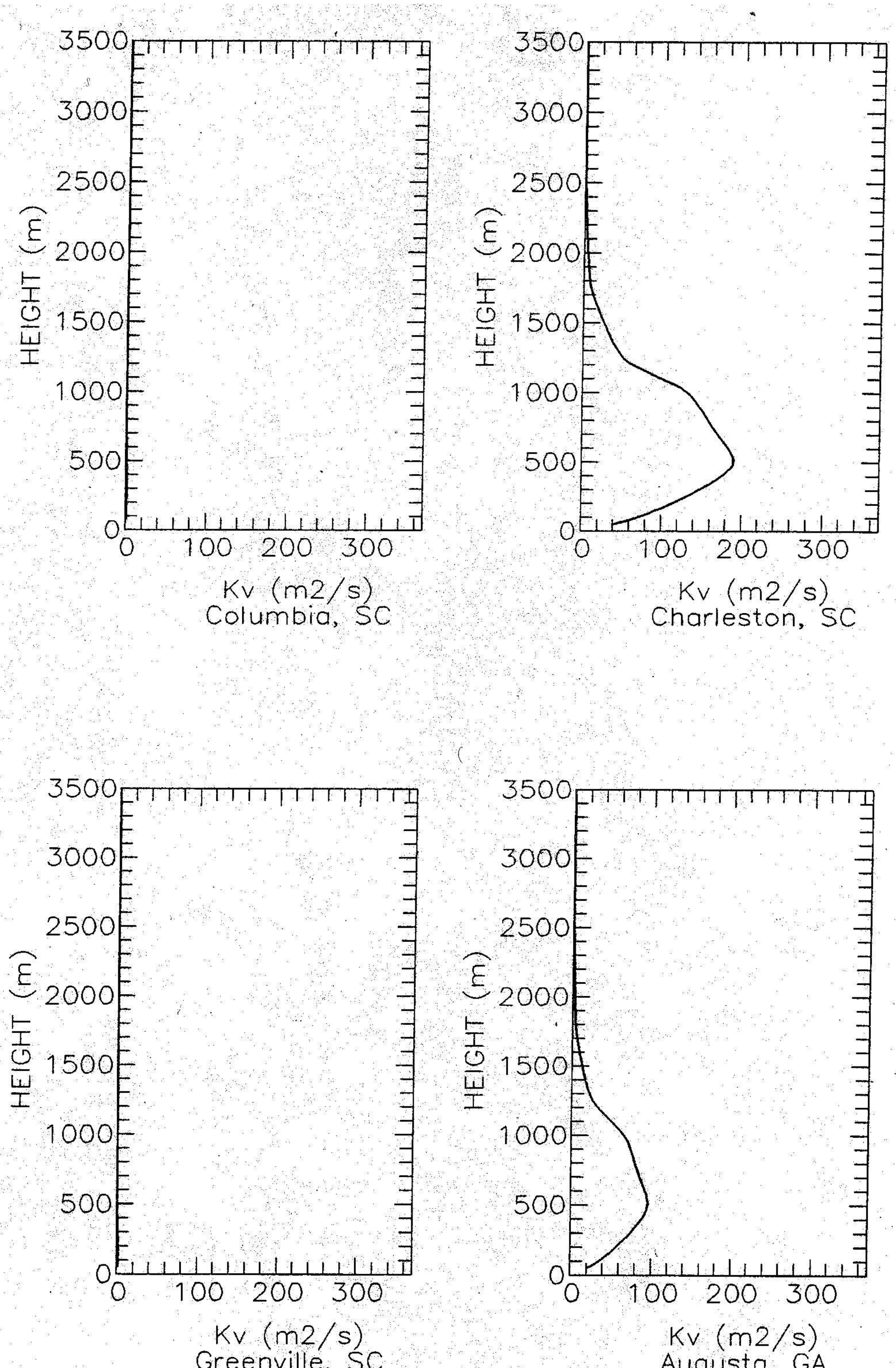

FIGURE 4–7h. Vertical diffusivities for Columbia, Charleston, and Greenville, SC, and Augusta, GA at 1300 EST on 980523.

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V. Air Quality, Land-Use, and Chemistry Input Preparation

In addition to the emission inventory and meteorological inputs, the UAM-V modeling system requires a number of additional input files. These contain information on: pollutant concentrations at the initial simulation time and along the boundaries of the modeling domain, land use, albedo, ozone column, photolysis rates, and chemical reaction rates. These additional inputs are described in this section of the report.

For ease of reading, all figures follow the text in this section.

A. Air Quality Related Inputs

Three UAM-V air quality input files define initial and boundary pollutant concentrations for each of the UAM-V state species, for the coarse grid only. The input file for initial conditions sets pollutant concentrations throughout the three-dimensional grid at the initial simulation time. The two boundary conditions files set concentrations along the lateral boundaries of the modeling domain for each hour of the simulation period, and along the top of the modeling domain for the entire simulation period.

Initial Conditions

For the SCDHEC application, the initial condition inputs for each simulation period were prepared using observed pollutant concentration data for monitoring sites located within the modeling domain. These data, valid at the initial simulation time (i.e., 0000 EST on the first day of the simulation) were obtained from the EPA Aerometric Information Retrieval System (AIRS). Species included ozone, NO, NO_2, and CO.

For the lowest model layer, the observed data were interpolated to the modeling domain, coarse grid only, using the standard UAM-V preprocessor program. This program relies on bilinear interpolation to estimate values of each species for each grid cell of the modeling domain. The surface layer values were also used for the second layer of the model, which extends from 50 to 100 m above ground. Above this, initial conditions were set equal to EPA default values for each pollutant species (EPA, 1991), with some lower values used for NO_x and CO. The initial values are: 40 ppb for ozone; 1 ppb for NO_x (0 ppb for NO, 1 ppb for NO_2); 25 ppb of hydrocarbons, divided among the lumped hydrocarbon species according to the default CB-IV speciation profile as given in EPA (1991); and 200 ppb of CO. After the initial base case simulation, it was decided to increase the initial ozone value first to 55 ppb and later to 60 ppb. The reason for this change is provided in the following subsection.

Boundary Conditions

The primary reason for using a nested-grid, regional-scale modeling configuration is to reduce the effects of uncertainty in the boundary conditions on the simulation results for the area of interest. Lateral boundary conditions need only be specified for the outermost (coarse-grid) domain. Top boundary conditions are specified for all domains using a single set of values. For this study, the lateral and top boundary concentrations for all pollutants were initially set equal to the values listed above. These were assumed to be representative of continental-scale background values.

The boundary condition value for ozone was subsequently updated for each simulation and simulation day using a “self-generating” boundary condition estimation technique. Using this technique, an average ozone concentration from the upper layer of the modeling domain is calculated for the last hour of each day, and is used to specify the ozone boundary value along the lateral and top boundaries for each subsequent day. As previously indicated, the initial value of ozone for the boundary conditions was updated to 55 ppb following the first full simulation of the episode period and then to 60 ppb later in the course of the diagnostic analysis. This decision came out of evaluation of the calculated ozone value for the remaining simulation days. In this manner, regional-scale build-up and/or lowering of ozone concentrations is represented in the simulations. The ozone boundary condition values for each day of the simulation period are listed in Table 5-1. Note that the values given in this table are for the base-case simulation.

Table 5-1.
Ozone concentrations used as boundary conditions for the base-case simulations, as calculated using the self-generating ozone boundary condition technique.

Date	Boundary Ozone (ppb)
5/16/98	60.00
5/17/98	58.03
5/18/98	61.31
5/19/98	63.78
5/20/98	66.15
5/21/98	67.14
5/22/98	65.76
5/23/98	64.87

The lack of pollutant concentration data (especially aloft), as well as the length of the simulation period, precludes a more detailed specification of the boundary conditions. However, given the geographical extent of the modeling domain beyond the primary area of interest, the coarse-grid boundary conditions were not expected to significantly influence the simulation results within the area of interest. In fact, increasing the initial ozone concentration from the EPA default of 40 ppb to 60 ppb did not significantly affect the results of the base case simulation in the areas of concern.

Quality Assurance of the Air Quality Inputs

Tabular summaries of the initial and boundary values for ozone, NO, NO_2, CO, and hydrocarbon species were prepared and reviewed. Stepwise quality assurance of the air quality input preparation procedures was also conducted.

B. Land-Use Inputs

A gridded land-use file is required for the full UAM-V domain and each subdomain. The land-use or surface characteristics file was prepared using 200-m resolution land-use data obtained from the U.S. Geological Survey (USGS). Each of the categories in the USGS land-use database was assigned to one of eleven UAM-V land-use categories. These include urban, agricultural, range, deciduous forest, coniferous forest (including wetlands), mixed forest, water, barren land, non-forest wetlands, mixed agricultural and range, and rocky (low shrubs). Table 5-2 lists the UAM-V land-use categories, along with the surface roughness and albedo values for each category.

Table 5-2.
Land-use categories recognized by UAM-V.
Surface roughness and UV albedo values are given for each category.

Category	Land-Use Description	Surface Roughness (m)	Albedo
1	Urban	3.00	0.08
2	Agricultural	0.25	0.05
3	Range	0.05	0.05
4	Deciduous forest	1.00	0.05
5	Coniferous forest including wetland	1.00	0.05
6	Mixed forest	1.00	0.05
7	Water	0.0001	0.04
8	Barren land	0.002	0.08
9	Nonforest wetlands	0.15	0.05
10	Mixed agricultural and range	0.10	0.05
11	Rocky (low shrubs)	0.10	0.05

The fraction of each of the eleven categories was then calculated for each grid cell and domain. A separate land-use file was prepared for each nested-grid subdomain. Gridded land-use fractions for each of the eleven categories are shown in Figure 5-1 for the outer grid, Grid 1. For this domain, the three largest land-use categories are water (45.7 percent), agricultural (17.9 percent) and mixed forest (11.3 percent). For Grid 2, the three largest are water (32.6 percent), agricultural (19.2 percent), and mixed forest (17.3 percent). The percentage of each land-use type for Grid 3 is listed in Table 5-3. Dominant land-use types for Grid 3 are agricultural (22.8 percent), coniferous forest (20.6 percent), and mixed forest (19.6 percent). Land use is used to determine deposition rates in the UAM-V model. It is also used to calculate albedo, as described later in this section.

Table 5-3.
Land-use distribution for SCDHEC Grid 3 using the UAM-V categories.

Category	Land-Use Description	Percent
1	Urban	4.2
2	Agricultural	22.8
3	Range	0.0
4	Deciduous forest	14.7
5	Coniferous forest including wetland	20.6
6	Mixed forest	19.6
7	Water	16.2
8	Barren land	0.1
9	Non-forest wetlands	1.1
10	Mixed agricultural and range	0.0
11	Rocky (low shrubs)	0.6

Quality Assurance of the Land-Use Inputs

Plots of the percentage distribution of land-use for each of the 11 land-use categories were prepared and examined. Stepwise quality assurance of the land-use input preparation procedures was also conducted.

C. Chemistry-Related Inputs

Application of the UAM-V modeling system requires preparation of several additional input files that contain information on albedo, ozone column, photolysis rates, and chemical reaction rates. This information is required for the full domain and each subdomain.

Albedo, Haze, Ozone Column Inputs

Ozone column data were obtained from the National Aeronautics and Space Administration (NASA) and the Earth Probe spacecraft data, available at jwocky.gsfc.nasa.gov. The range of ozone column values for the entire domain and simulation period were calculated for use in the photolysis rate preprocessor program. The resulting five binned values are 302, 309, 316, 323, and 333 Dobson units. The haze parameter for UAM-V (aerosol optical depth) was set to 0.094 (a value typical of rural conditions) for the entire modeling domain. Albedo is automatically assigned to each grid cell base on land use by the albedo/haze/ozone column processor program.

Chemistry Parameters

In combination with the albedo/haze/ozone column file, two additional inputs determine the chemical rates used by UAM-V. Photolysis rates are calculated as a function of albedo, haze, ozone column, height, and zenith angle. Photolysis rates were calculated using the designated UAM-V preprocessor program, utilizing the values of albedo, haze, and total ozone column information discussed above.

Additional chemistry parameters determine the rates and temperature dependence for the remaining reactions. Chemical reaction rates, activation energies, and maximum/minimum species concentrations, as used in the validation of the CBM-IV chemical mechanism against smog chamber data, were utilized along with appropriate updates for the enhanced treatment of radical-radical termination reactions, isoprene, and toxics chemistry.

Quality Assurance of the Chemistry-Related Inputs

The ozone column values and photolysis rates were tabulated and examined. Stepwise quality assurance of the chemistry-related input preparation procedures was also conducted.

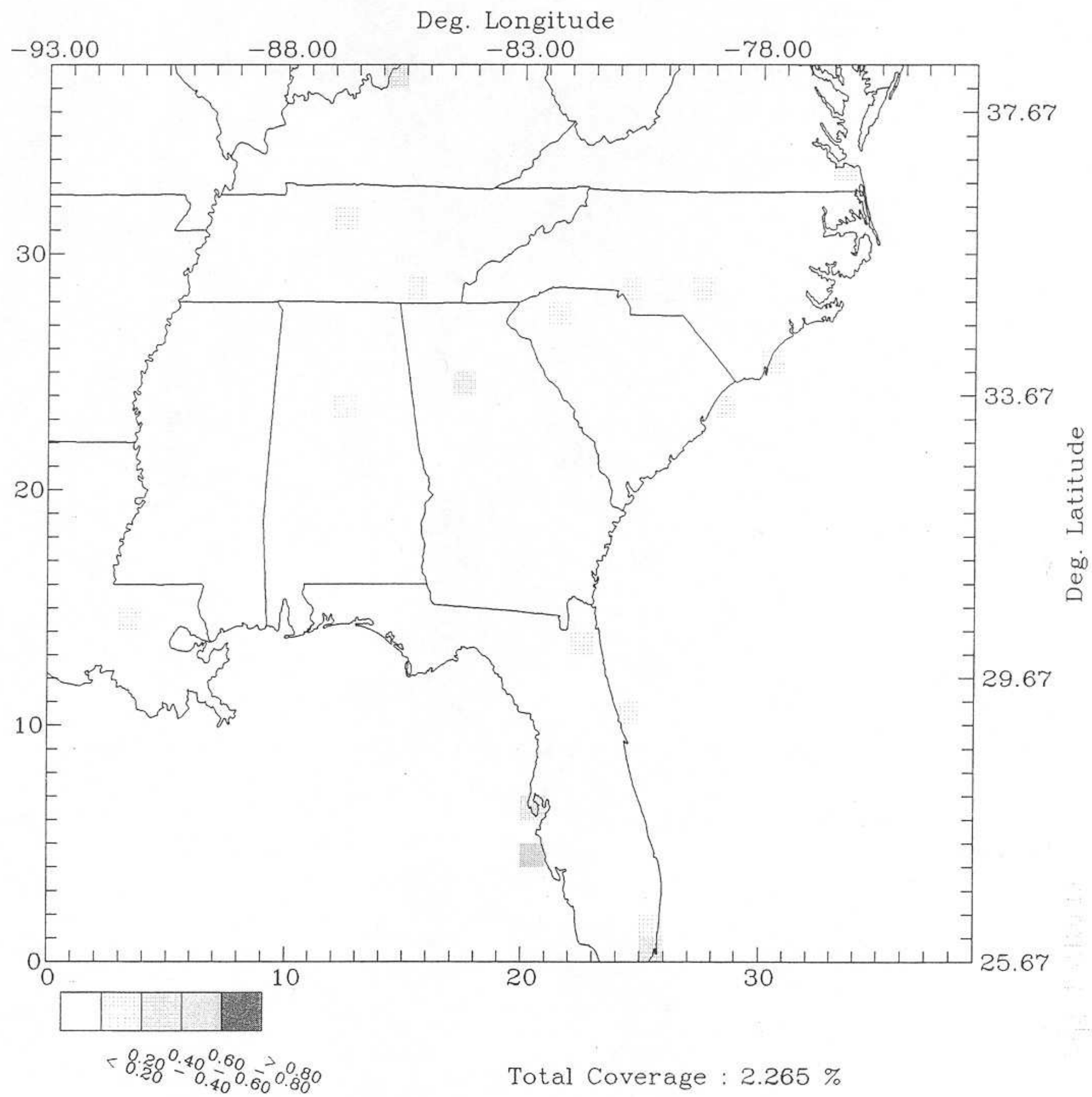

FIGURE 5-1a. Land use for SCDHEC Grid 1 (36 km resolution): Urban

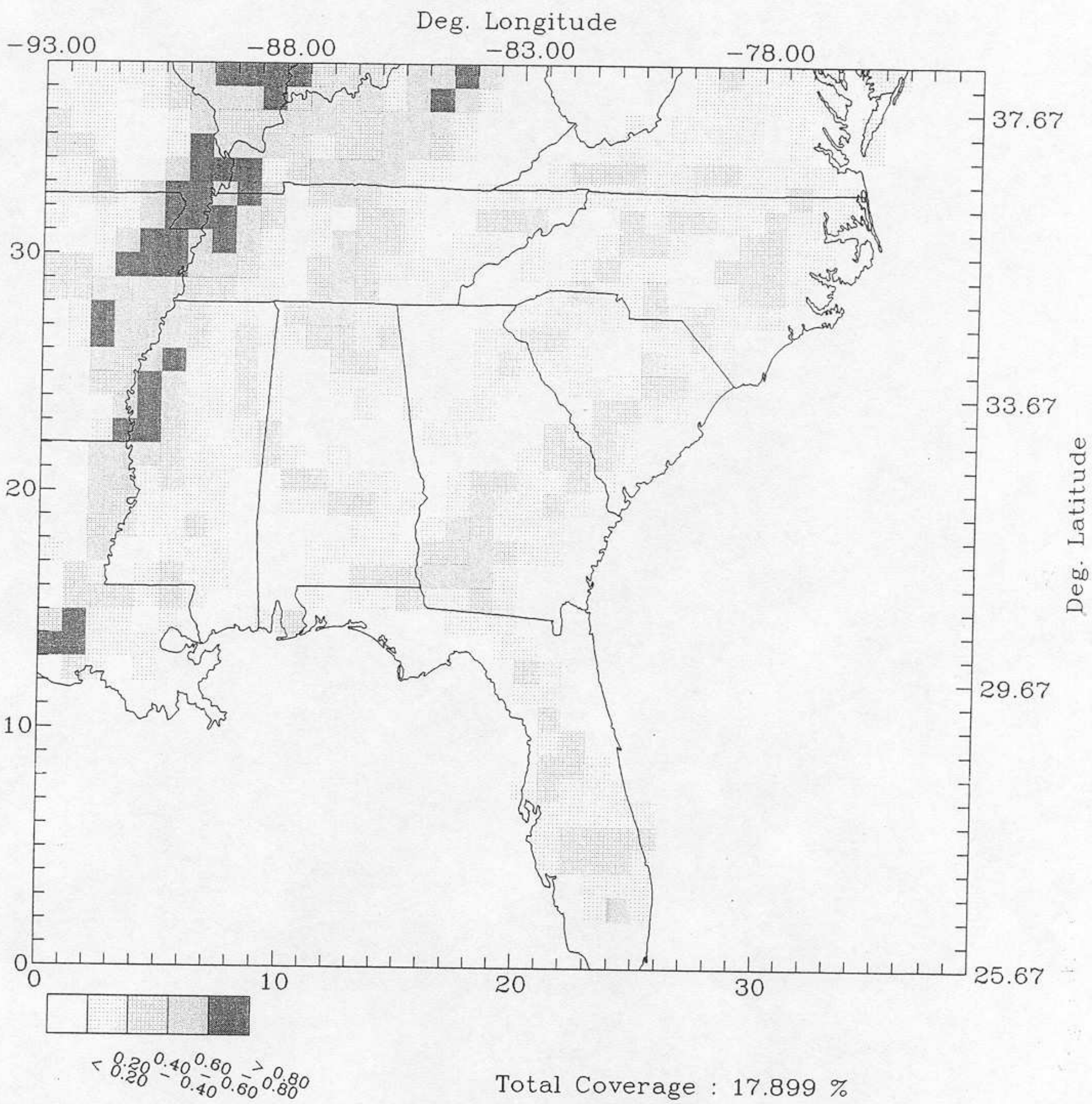

FIGURE 5-1b. Land use for SCDHEC Grid 1 (36 km resolution): Agriculture

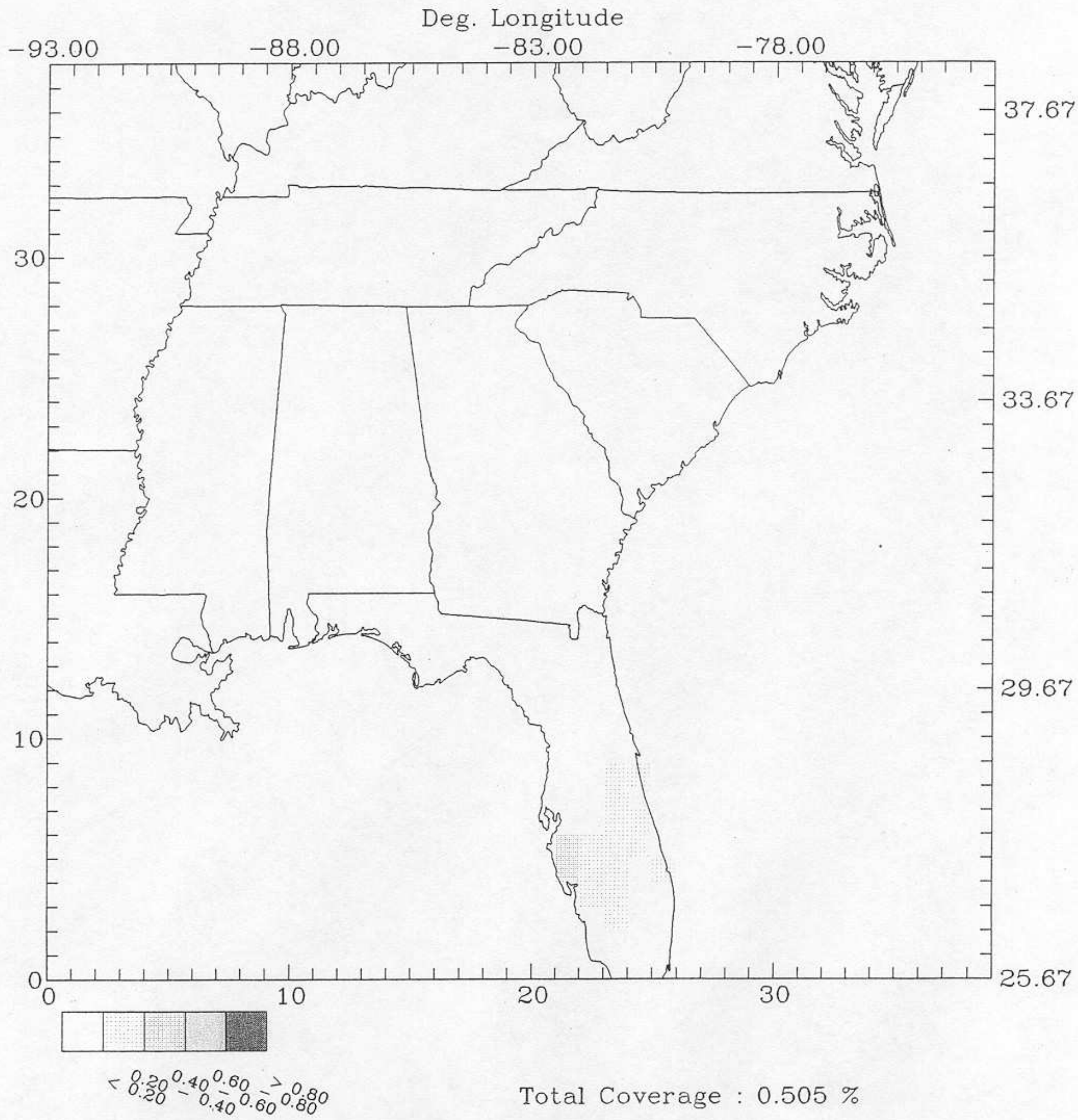

FIGURE 5-1c. Land use for SCDHEC Grid 1 (36 km resolution): Range

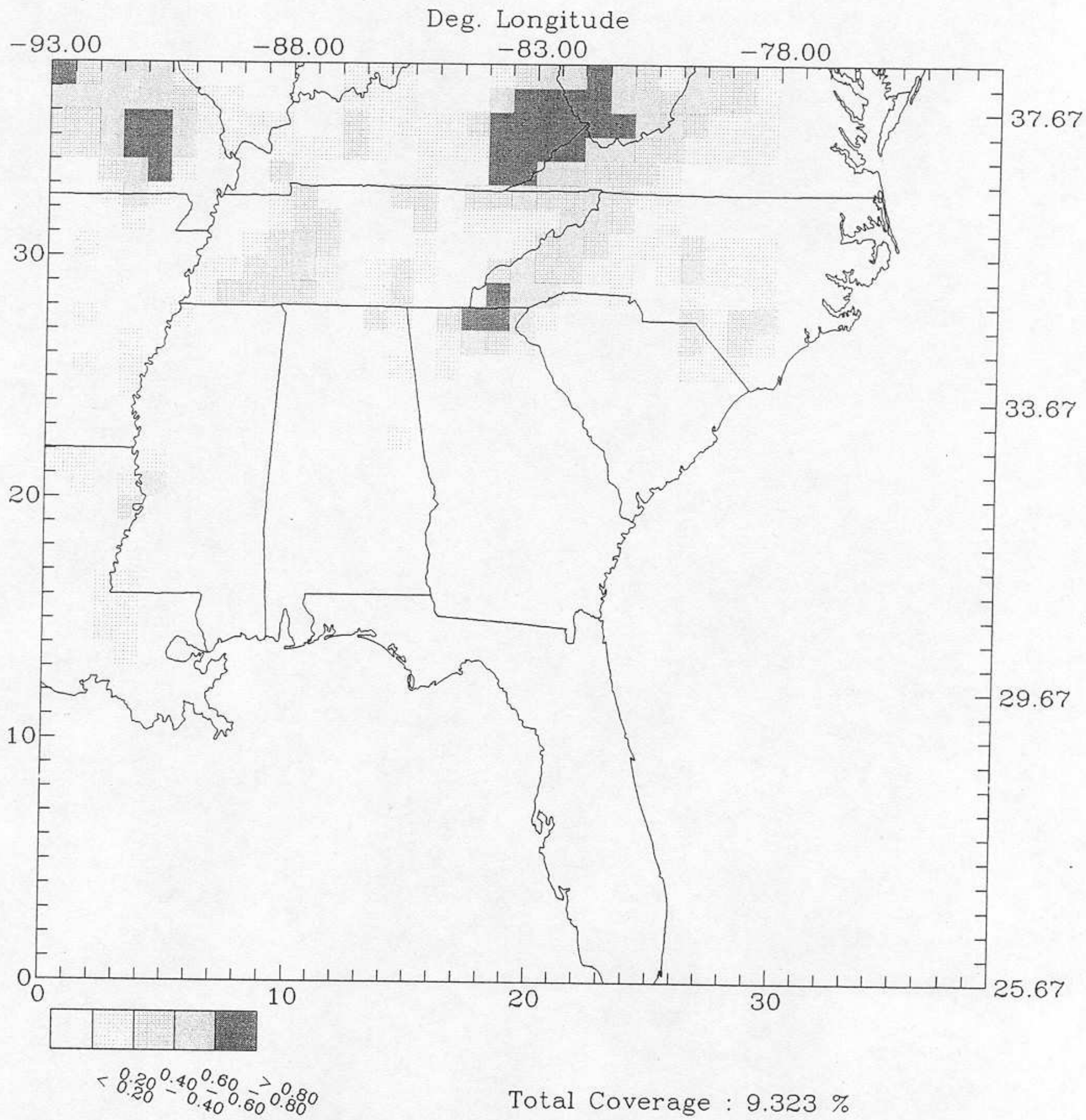

FIGURE 5-1d. Land use for SCDHEC Grid 1 (36 km resolution): Deciduous Forest

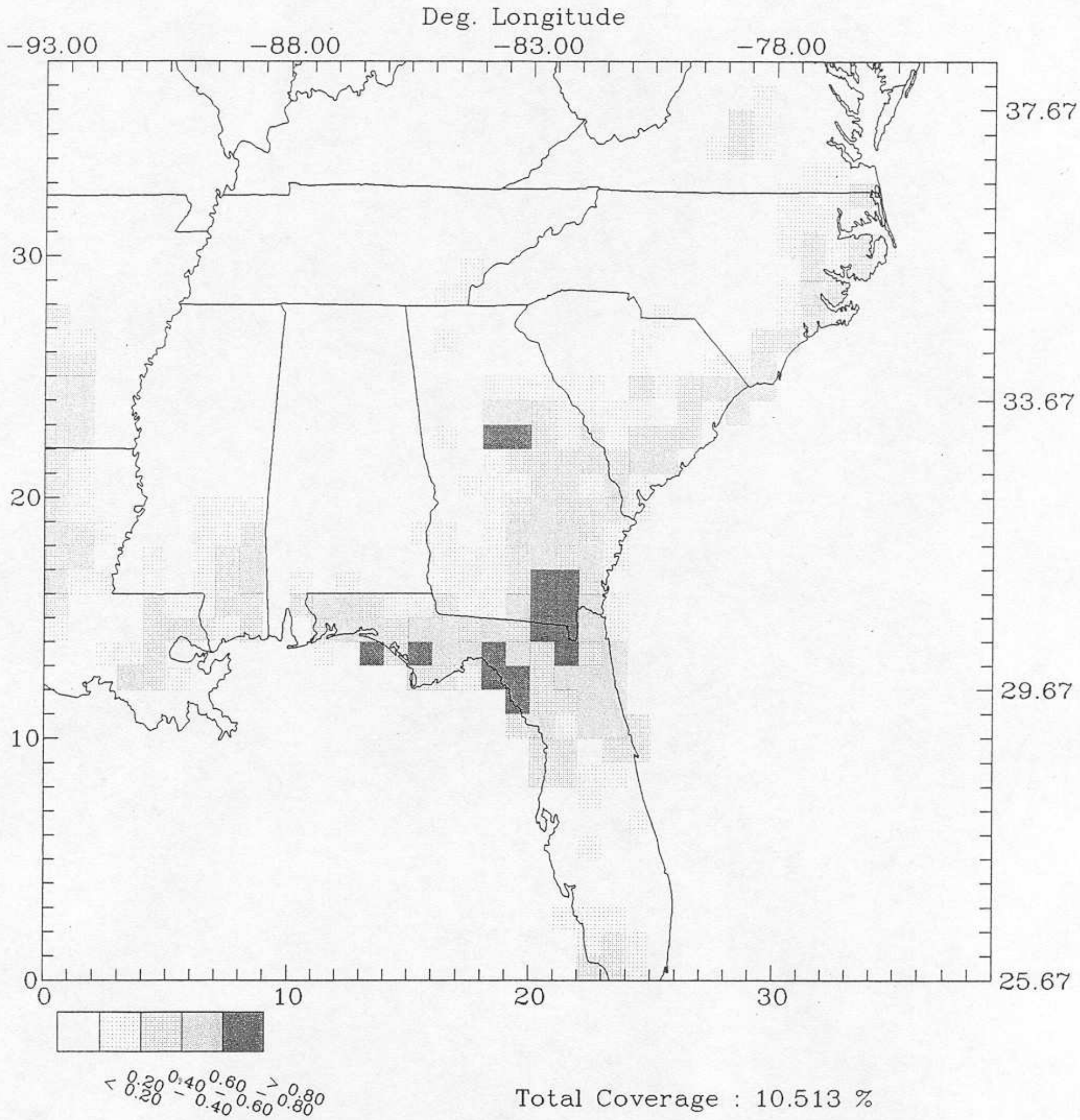

FIGURE 5-1e. Land use for SCDHEC Grid 1 (36 km resolution): Coniferous Forest

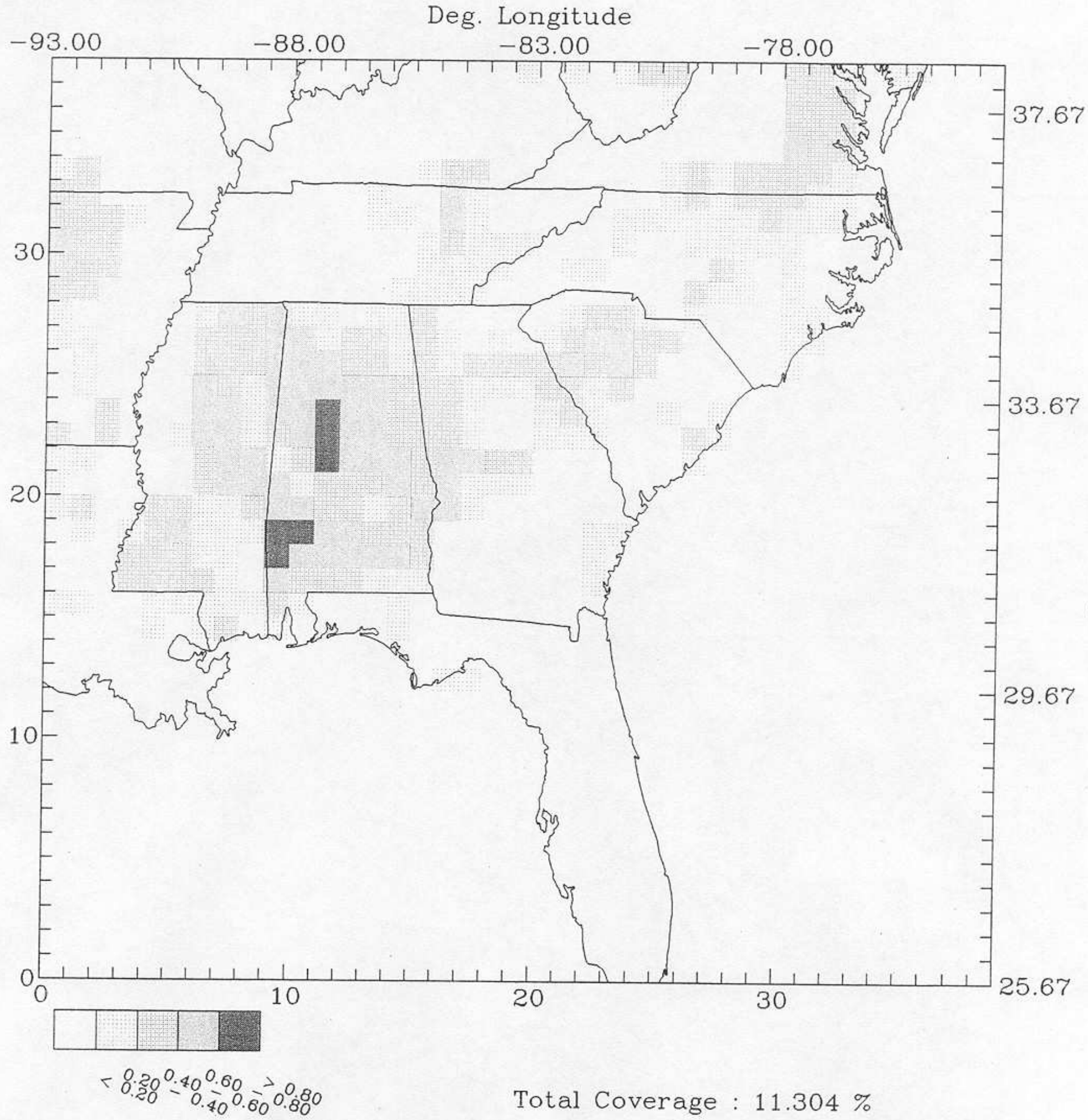

FIGURE 5-1f. Land use for SCDHEC Grid 1 (36 km resolution): Mixed Forest

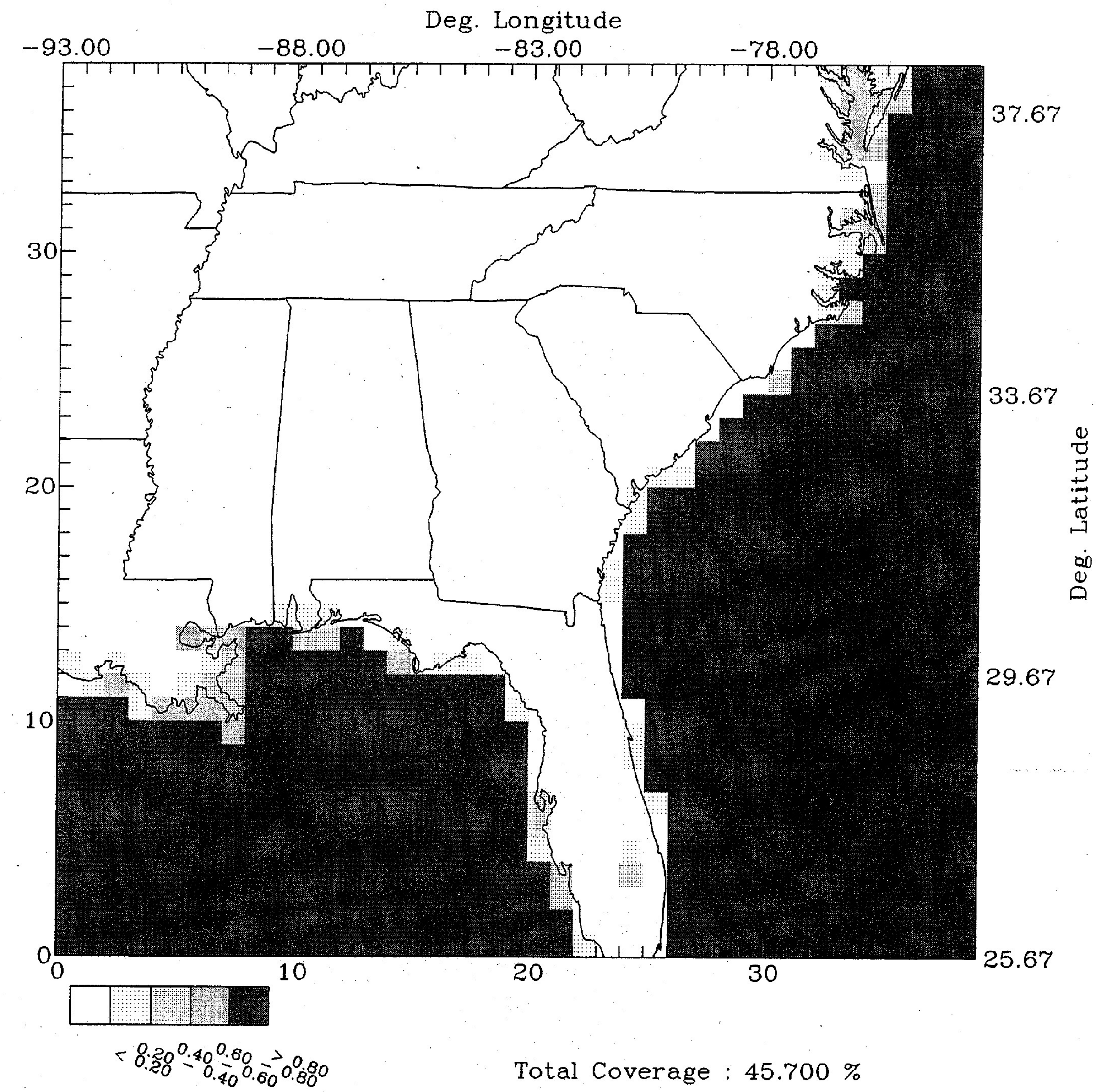

FIGURE 5-1g. Land use for SCDHEC Grid 1 (36 km resolution): Water

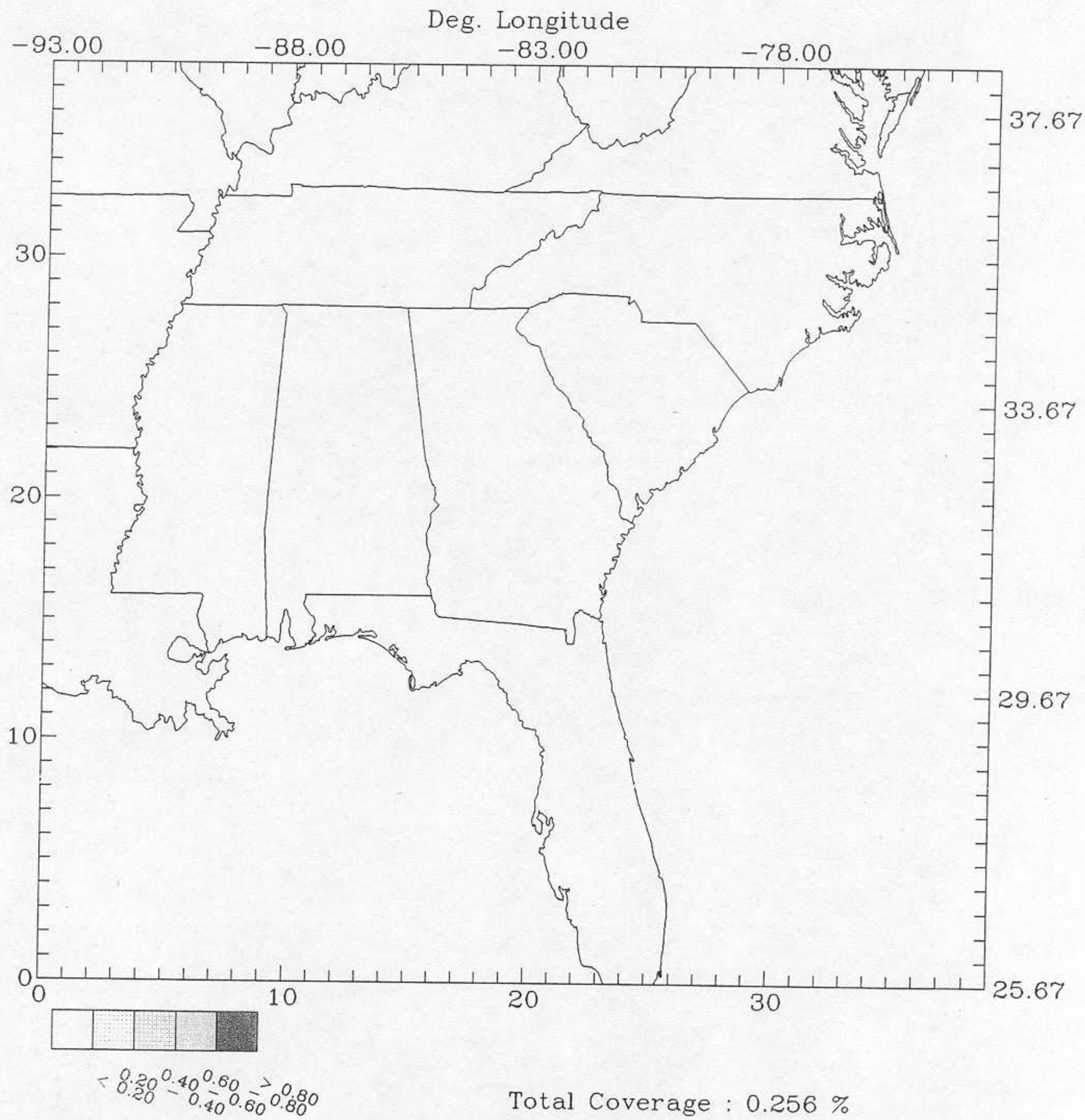

FIGURE 5-1h. Land use for SCDHEC Grid 1 (36 km resolution): Barren Land

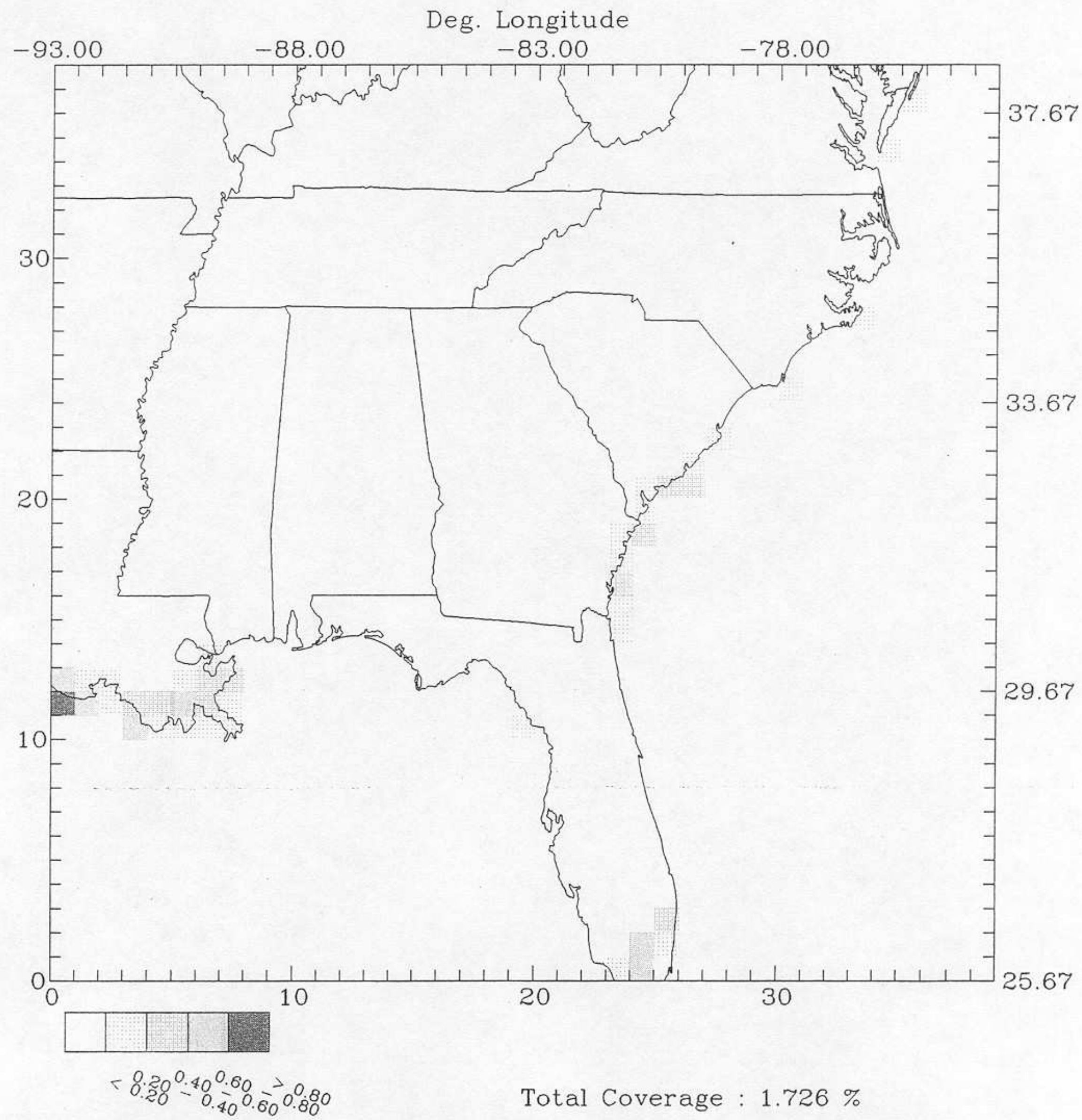

FIGURE 5-1i. Land use for SCDHEC Grid 1 (36 km resolution): Nonforest Wetlands

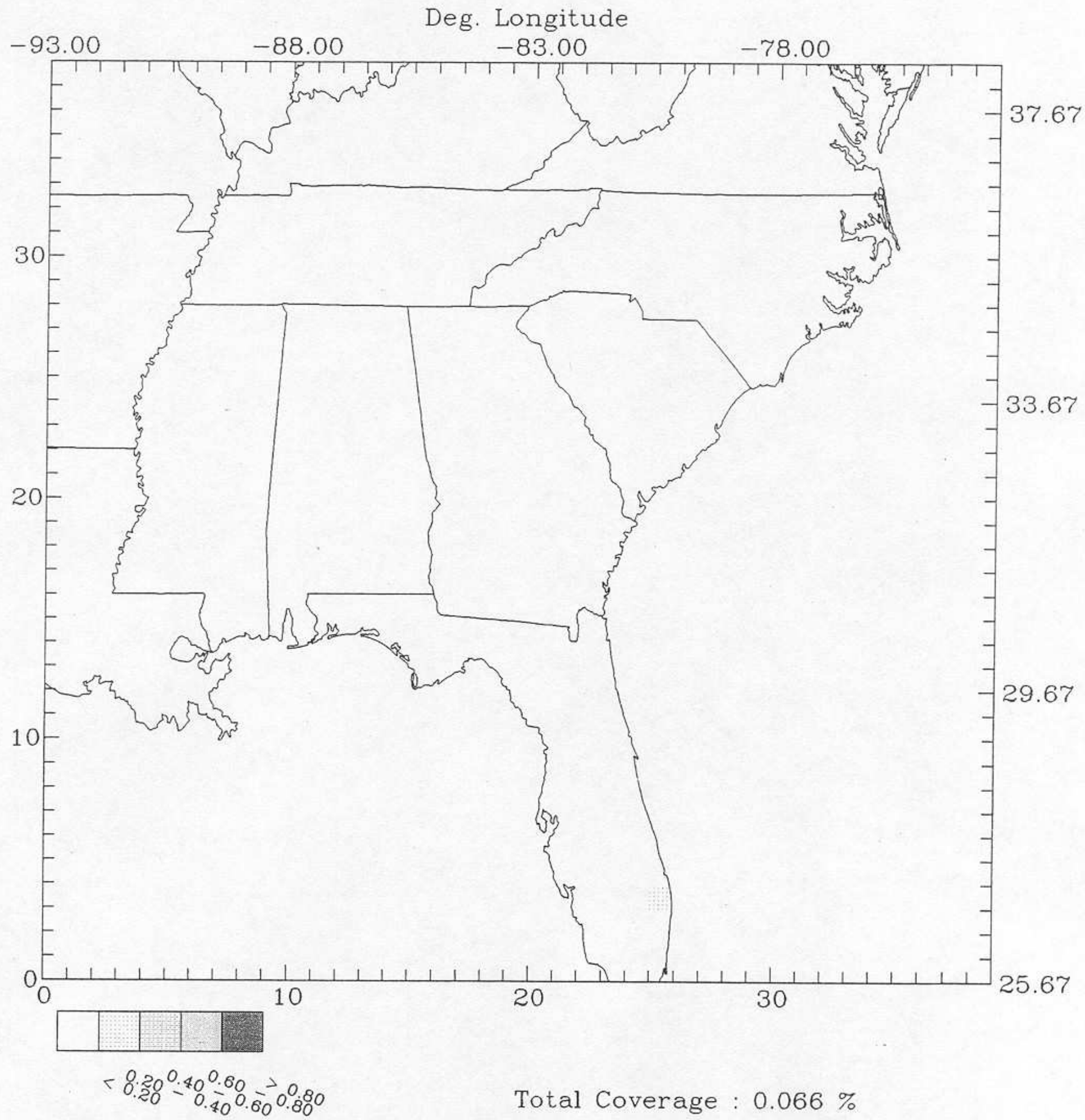

FIGURE 5-1j. Land use for SCDHEC Grid 1 (36 km resolution): Mixed Ag & Range

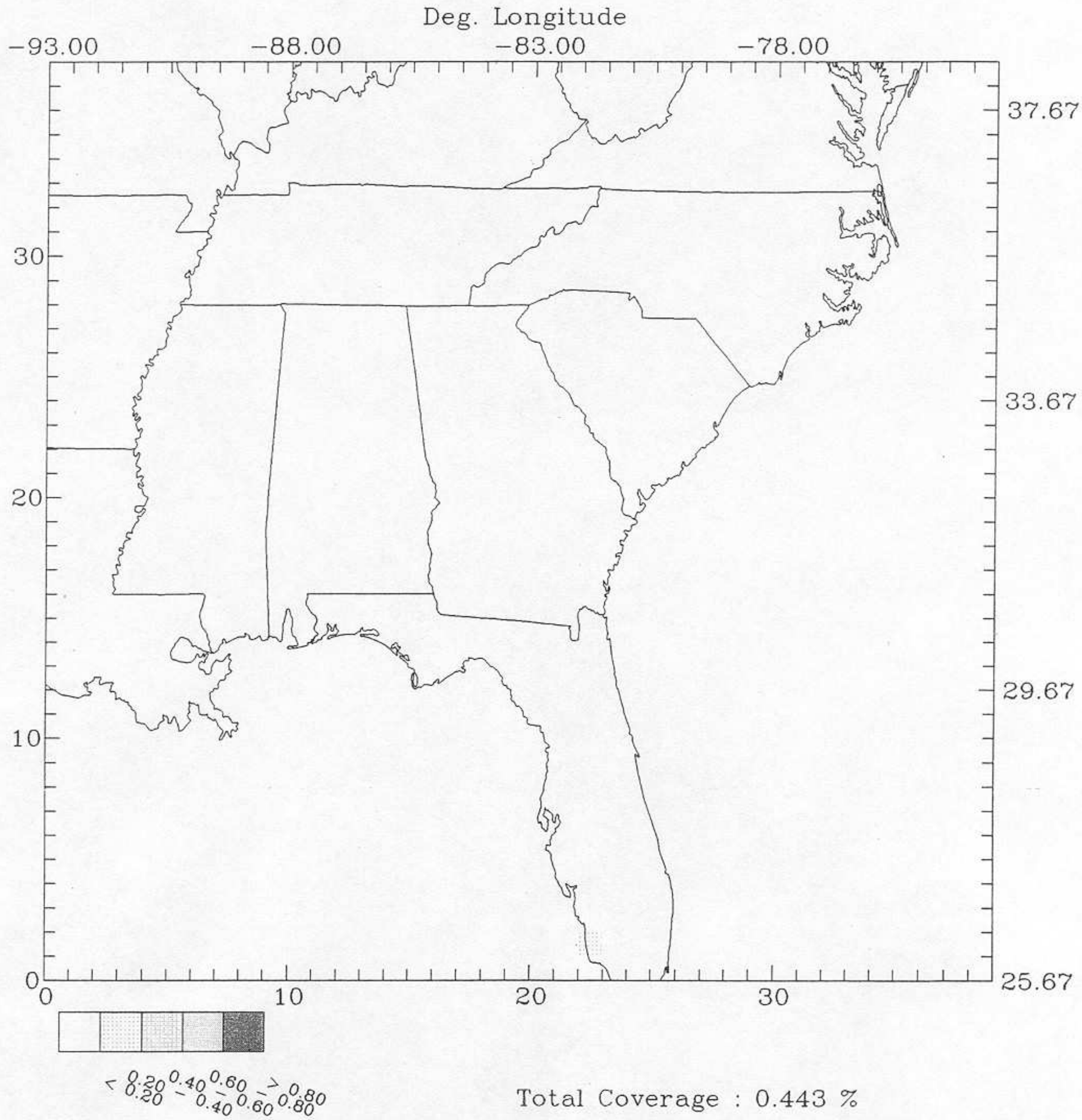

FIGURE 5-1k. Land use for SCDHEC Grid 1 (36 km resolution): Rocky (Low Shrubs)

VI. Model Performance Evaluation

The first stage in the application of the UAM-V modeling system for ozone air quality assessment purposes consists of an initial simulation and a series of diagnostic and sensitivity simulations. These simulations are aimed at examining the effects of uncertainties in the inputs on the simulation results, identifying deficiencies in the inputs, and investigating the sensitivity of the modeling system to changes in the inputs. Model performance for each simulation is assessed through graphical and statistical comparison of the simulated pollutant concentrations with the observed data obtained from available monitoring stations located throughout the domain. The results of this comparison are used to assess whether the model is able to adequately replicate the air quality characteristics of the simulation period and to determine whether additional diagnostic and sensitivity simulations are needed.

Once the results of the graphical, statistical and sensitivity analysis show acceptable performance of the model for a given simulation, that simulation is called the "base case" simulation and the modeling analysis moves to the next stage. This next stage consists of projection and modification of the emission inventory inputs to assess the effects of changes in emissions on future air quality. Boundary condition inputs may also be modified to reflect future-year conditions.

Considerable time and effort are spent in the design and conduct of the base-case diagnostic and sensitivity analysis, and in the evaluation of the base-case simulation. Reasonable model performance is critical to the reliable use of the modeling system to assess the effects of changes in emissions on future air quality.

The base-case application of the UAM-V modeling system for the South Carolina modeling analysis included an initial simulation, several diagnostic/sensitivity simulations, a final base-case simulation, and the graphical and statistical analysis of each set of modeling results, including the comparison with observed air quality data. The procedures and results of the base-case modeling analysis are presented and described in this section. Most of the discussion pertains to ozone since it is the primary pollutant of interest.

For ease of reading, all figures are presented following the text of this section. Plots are provided for Grids 1, 2 and 3. Refer to Figure 1-2 for a plot of the full South Carolina modeling domain.

Initial Simulation Results

The initial simulation serves several purposes. Initial application of the UAM-V model can reveal format problems or simple errors in the input files or parameters. The results of this simulation provide a basis to check for gross errors or problems in the input files and guide the more detailed review/refinement of the inputs that occurs throughout the base-case modeling effort.

The initial UAM-V simulation results for the May 1998 modeling episode period (not shown) are characterized by generally good agreement with observed ozone concentration levels in the outermost and intermediate grids. However, peak ozone values are generally underestimated for days 18, 19 and 20 May in several areas throughout the regional scale domain. Within Grid 3, the primary area of interest, model performance varies among the simulation days and among the areas. For many of the sites the model tends to underestimate the peak concentrations, especially on 18 and 19 May. The model performs very well for the last 2-3 days of the simulation for most sites. The gradients indicated by the observations are well depicted for all days (i.e., the model is able to distinguish between areas of high and low ozone). Nighttime observations are overestimated for some (mostly rural) sites.

Based on these initial simulation results for the May 1998 episode period, the diagnostic and sensitivity analysis for this episode period was initially designed to examine meteorological (especially the K_v and wind fields) and boundary condition inputs, since these key inputs can directly influence simulated ozone concentration levels. The emission inventory was also further analyzed and reviewed. The effect of solar radiation on the calculation of biogenic emissions was also investigated.

Diagnostic and Sensitivity Analysis

The diagnostic and sensitivity simulations performed for this modeling episode period can be generally characterized according to the type of input that was adjusted or modified. A brief summary of the key diagnostic and sensitivity simulations for this episode is provided. The simulation results were analyzed in each case using a variety of graphical and statistical analysis procedures. In addition, as part of the diagnostic analysis, the UAM-V process analysis feature was used to examine the simulation results at the simulation-process level.

Meteorology-Related Sensitivity Simulations

Meteorological fields were revised on two occasions. Both revisions involved the use of alternative postprocessing procedures, as discussed in Section 4 of this report. First, the vertical exchange coefficient (K_v) fields were normalized for all grids, to ensure that the maximum value generated by MM5 was represented in the UAM-V ready K_v fields, and not smoothed away by interpolation. Second, similarity theory was applied to the surface wind fields, to better represent the wind speeds within the lowest UAM-V layer. Both of these modifications to the postprocessing of the MM5 fields are described in more detail in Section 4. Use of these alternative procedures did not significantly affect performance of the model over the area of interest enclosed by Grid 3. Modification of the K_v profile increased the ozone concentrations slightly.

Initial- and Boundary-Condition-Related Diagnostic and Sensitivity Simulations

The “self-generating” ozone boundary conditions technique, described in a previous section, avoids the arbitrary specification of the base-case boundary conditions (in the absence of upper-air pollutant concentration data) and the subsequent adjustment of the values for future-year simulations. The boundary condition values for the initial simulation showed a rapid increase from 40 to about 55 ppb during the first few days of the simulation. Subsequent simulations showed that the concentrations tended to stabilize around 60 ppb. Consequently, a value of 60 ppb was used as the initial value for the self-generating boundary ozone concentration. The day-to-day variation in this value for the final base-case simulation is provided in Section 5, Table 5-1. The values provided in this table were used to represent the regional-scale ozone concentrations aloft for the simulation period. Use of the higher ozone concentration values increased ozone levels slightly throughout the domain and simulation period, compared to the initial simulation and results, and provided improved model performance for the areas of interest in Grid 3. Within the areas of interest, maximum ozone concentrations were increased by about 2-4 ppb, on average. These results indicate that, for this domain and simulation period, the ozone boundary conditions (as used to represent the regional-scale ozone concentration levels) have a slight but non-negligible influence on the simulated ozone concentrations. Prior to and during the first days of the simulation period, an important fire episode occurred in Central America. Emissions from wildfires are often associated with higher-than-normal observed ozone values in areas affected by the smoke plume, due to enhanced carbon monoxide (CO) and hydrocarbon emissions that are contained within the plumes. Analysis of observed carbon monoxide, a pollutant present in high concentrations during fire episodes, revealed high values of this pollutant at many stations during the initial days of the simulation, especially days 18 and 19 May. In addition to ozone, these high observed CO values were also underestimated by the modeling system during these days. It was decided to explore the impact of this fire episode on the underestimation of ozone and CO values for the first few days of the simulation.

Two sensitivity simulations were conducted for that purpose. In both cases, only the first four days of the simulation period were modeled. In the first of these, CO concentrations in the initial and boundary conditions files were raised from the background value of 200 ppb to 800 ppb, to better represent the presumed high background levels of carbon monoxide due to the fire episode. Results from this four-day simulation showed that simulated ozone levels at many of the sites of interest increased to levels closer to observed ozone values. Since the simulated carbon monoxide concentrations were still lower than the observed values at many sites, it was decided to further increase the CO boundary concentration from 800 ppb to 1200 ppb. The results again showed a better simulation of the observed ozone and CO values for the initial days of the simulation. Table 6-1 shows a comparison of selected statistics for Grid 3, for the base-case run and the two sensitivity runs with 800 ppb and 1200 ppb of CO in the boundary condition. The average accuracy of the peak measures how well the observed peaks are represented (averaged across all sites) while the normalized bias considers the representation of the hourly ozone values. Both measures improve (their value is reduced) for days 18 and 19 May, indicating better performance of the model, on average. For the initial days of the simulation, 16 and 17, the change in performance is mixed, indicating that the influence of the fires may have been introduced too early in the sensitivity simulations.

Table 6-1.
Statistical measures for the base-case, 800 ppb CO, and 1200 ppb CO simulations.

Date	Avg Acc. Peak (%) - Base Case	Avg Acc. Peak (%) - 800 ppb CO	Avg Acc. Peak (%) - 1200 ppb CO	Normalized Bias (%) - Base Case	Normalized Bias (%) - 800 ppb CO	Normalized Bias (%) - 1200 ppb CO
980516	-5.4	5.0	10.3	-8.7	-0.5	3.5
980517	-4.8	8.2	12.9	-0.7	8.2	12.8
980518	-16.0	-7.6	-3.6	-14.1	-6.6	-2.7
980519	-16.9	-10.0	-6.2	-14.6	-7.5	-3.8

These results seem to support our theory that high background levels of carbon monoxide in the domain created by a fire episode in Central America may be responsible for the underestimation of observed peak ozone levels at many sites in the domain for the initial days of the simulation (in particular, 18 and 19 May).

Emissions-Related Diagnostic and Sensitivity Analysis

The base-case emissions were updated on two occasions. First, biogenic emissions were re-processed using a 4-km resolution land-use/crop database provided by EPA. Previously, a 12 km resolution land crop data was used. This new land-use/crop database was designed to enhance the application of the Biogenic Emissions Inventory System (BEIS) and is expected to provide a greater level of detail and a more accurate depiction of the land/crop use in the domain. Use of an updated version of the BEIS (BEIS-3) program was explored, but adapting the existing code to the South Carolina modeling system platform would have required extensive work and was beyond the scope of this project. Instead, revised biogenic emissions files were created using the 4 km resolution land-use and crop data and the BEIS-2 program. Overall biogenic hydrocarbon emissions were reduced by approximately 5 percent for each simulation day. The biogenic emissions estimated with and without the high resolution land-use and crop data are compared in Table 6-2. The impact of the revised biogenic emissions on the simulation results was small and always toward lower values of ozone, thus, slightly degrading model performance. Nevertheless, the higher resolution biogenic emissions were used for the final base-case simulation.

Table 6-2.
Comparisons of biogenic VOC emissions for Grid 3, revised vs. original biogenics. Emissions in tons/day.

	980516	980517	980518	980519	980520	980521	980522	980523
Rev Bio	21777	18505	19885	21567	18982	24258	17438	13491
Org Bio	22996	19651	20965	22805	20010	25595	18351	13877

Second, mobile-source emissions were re-processed using the most recent version of the MOBILE6 code released by EPA in January 2002. Mobile-source NO_x emissions were increased by 17 percent for each simulation day; hydrocarbon emissions were decreased by 7 percent. Mobile-source emissions of NO_x, VOC, and CO for each simulation day are compared for MOBILE5b and MOBILE6 in Table 6-3. The increase in NO_x emissions is in line with changes in a number of assumptions, including: updated facility-based emission factors (different average emissions for different roadway types), new diurnal emission factors, updated effects of oxygenated fuels on CO, updated effects on fuel sulfur content, separation of “start” and “running” emissions, and updates to a few other assumptions (such as driving cycle assumptions) based on new data. The impact of the increased mobile emissions on the simulated ozone concentrations was in general small and mostly toward higher values of ozone (increases of around 1 to 2 ppb at most sites).

Table 6-3.
Comparisons of on-road mobile source emissions for Grid 3 using MOBILE 6 vs. MOBILE 5b. Emissions in tons/day.

	980516	980517	980518	980519	980520	980521	980522	980523
NOX								
MOBILE 6	1608	1407	1692	1725	1708	1742	1859	1608
MOBILE 5b	1380	1207	1452	1480	1466	1495	1595	1380
VOC								
MOBILE 6	1110	971	1167	1191	1179	1202	1283	1110
MOBILE 5b	1190	1042	1252	1277	1265	1290	1376	1190
CO								
MOBILE 6	11615	10163	12220	12462	12341	12583	13430	11615
MOBILE 5b	9162	8017	9639	9830	9734	9925	10593	9162

An additional emissions-related sensitivity simulation was performed as part of the South Carolina 8-hour ozone modeling analysis. The emission of isoprene by vegetation is closely associated with solar radiation. High solar radiation leads to higher emissions of isoprene and vice versa. SAI found through work on another project that use of a new radiation scheme in MM5 tends to give higher solar radiation values that the scheme used for the South Carolina application. The values were as much as 50 percent greater for some areas, but different simulation dates for the two projects did not allow a direct comparison of the solar radiation values. Within BEIS, and for typical temperature ranges, changes in isoprene emissions are proportional to changes in solar radiation. Therefore, to explore the potential effects of this increase in solar radiation values, isoprene emissions were increased by 50 percent for all grids and a four-day simulation was performed. In the sensitivity simulation, maximum ozone concentrations were increased by approximately 2 to 16 ppb throughout the domain, with some larger increases (on the order of 16 to 34 ppb) occurring for some areas and days. For numerous reasons, biogenic emissions represent one of the greatest sources of uncertainty in the emissions inventory and the modeling results. The results of this simulation highlight the possible effects of this uncertainty on simulated ozone concentrations and model performance.

Summary of Base-Case Model Performance

The assessment of base-case model performance evaluates the performance on both a regional and sub-regional scale. Grid 1 provides a perspective on regional-scale performance, Grids 2 and 3 on sub-regional-scale performance. For this project, Grid 3 received special attention, since it encloses South Carolina (Aiken/Augusta, Anderson/Greenville/Spartanburg, Columbia, Florence/Darlington, Rock Hill, and Charleston areas) and parts of Georgia (Atlanta area) and North Carolina (Raleigh-Durham and Charlotte).

The Grid 1 evaluation focuses on whether the modeling system is able to represent the observed regional-scale ozone concentration patterns and the day-to-day variations in the concentrations and concentration patterns. For Grids 2 and 3 a more detailed analysis of model performance was conducted with respect to spatial and temporal ozone concentration patterns and domain-wide and site-specific peaks. Statistical measures of model performance were also compared with available EPA recommended ranges. For 1-hour ozone, these are as follows: domain-wide unpaired accuracy of the peak (±20 percent), normalized bias (± 15 percent), and normalized gross error (35 percent). For 8-hour ozone, the accuracy of the 8-hour maximum values averaged (1) over all sites in a given domain and (2) over all days for a given site is expected to be within ± 20 percent. The evaluation of model performance focuses on 1-hour ozone concentrations and the ability of the modeling system to represent 8-hour average concentrations.

Analysis of Regional-Scale Performance (Grid 1)

For this grid, graphical and statistical analysis of the simulation results was used to assess whether the spatial ozone concentration patterns are consistent with the observed data and whether the simulation represents the domain-wide magnitude and day-to-day differences in the ozone concentrations. In the following discussion, emphasis is placed on regional-scale patterns. Specific patterns limited to the location of Grid 2 and Grid 3 are discussed in more detail later in this section.

Daily maximum simulated ozone concentration plots for Grid 1 for each simulation day for the May 1998 modeling episode period are presented in Figure 6-1. The isopleths represent the 1-hour maximum simulated ozone concentrations, and the numerical values represent the corresponding maximum observed concentrations. The domain-wide maximum and minimum values are provided in the upper right-hand corner of the plot. Note that the simulated values are derived from the results for both Grid 2 and Grid 3. These plots emphasize the variability of the concentrations throughout the region (both simulated and observed) that are attributable to the variable distribution of emissions sources.

For this domain, the simulated concentration fields are characterized by higher ozone concentrations around urban areas of Georgia (Atlanta metropolitan area), Alabama (Birmingham), Florida, South Carolina, and North Carolina, and around coastal areas such as the Gulf Coast and much of the East Coast. In addition, there is evidence of simulated ozone transport from high-activity areas in the form of plumes that clearly follow the wind patterns that occurred during the simulation period. Under conditions of westerly to southwesterly winds (as occurred during 20-22 May), some of the highest ozone values tend to occur in eastern Georgia. The concentration patterns clearly suggest ozone and/or ozone precursor transport from the Atlanta area toward South Carolina.

Notice that for areas covered by finer grids, the higher resolution translates into additional complexity in the ozone concentrations patterns. Consequently, most of the more detailed patters occur in, but are not limited to, those areas covered by Grid 2 and, especially, Grid 3 (refer to Figure 1-1 for a plot of the UAM-V modeling domain and grid configuration)

Comparison with the observed ozone concentration data shows that the 1-hour maximum simulated concentrations tend to be lower than observed during the first part of the simulation period (through approximately 19 May) and consistent with or slightly higher than the observed values during the remainder of the simulation period. More detailed comments on model performance for areas located in the finer grids appear later in this section.

The metrics and statistical measures used in the evaluation of model performance are listed and described in Table 6-4. A subset of these corresponding to 1-hour ozone for Grid 1 for the May 1998 modeling episode period is provided in Table 6-5a. The relative statistical measures were calculated for simulation/observation pairs for which the observed value was greater or equal to 40 ppb, in accordance with EPA modeling guidance (EPA, 1991). For the May 1998 base-case simulation for Grid 1, the average observed value is higher than the simulated value for all but the last day of the simulation, but the difference is small. The unpaired accuracy of the peak is well within the EPA recommended range of 20 percent for all simulation days, indicating good performance at the peaks. However, this parameter may not be meaningful for such a large regional domain, especially if the simulated and observed peaks are not collocated or nearly collocated. The normalized bias indicates that the concentrations greater than 40 ppb are mostly underestimated. However, for all days, the normalized bias and gross error are within the EPA recommended ranges of ±15 and 35 percent, respectively.

Table 6-4.
Definition and description of measures/metrics used for model performance evaluation.

Metric	Definition
Threshold value	The minimum observation value used to calculate statistics
# of data pairs	The number of data pairs with observations greater than or equal to the threshold value
Maximum observation (ppb)	Maximum concentration at an observation site
Maximum domain-wide simulation (ppb)	The maximum simulated concentration in the domain
Time of peak observation (hr)	The hour at which the maximum observed concentration occurs
Time of peak simulation (hr)	The hour at which the simulated value corresponding to the observed maximum occurs
Mean observation value (ppb)	The average observed concentration above the threshold value
Mean simulation value (ppb)	The average simulated concentration corresponding to observations above the threshold
Unpaired accuracy of the peak	$\frac{S_{Max} - O_{Max}}{O_{Max}}$ where S_{Max} is the maximum simulated value and O_{Max} is the maximum observation.
Normalized bias	$\left(\frac{1}{N}\right)\sum_{l=1}^{N}(S_l - O_l)/O_l$ where N is the number of data pairs, and S_l and O_l are the simulated and observed values at site l, respectively.
Gross error	$\left(\frac{1}{N}\right)\sum_{l=1}^{N}\lvert S_l - O_l\rvert/O_l$
Average accuracy of the peak	$\left(\frac{1}{N}\right)\sum_{l=1}^{N}(S_{Ml} - O_{Ml})\Big/O_{Ml}$ where S_{Ml} and O_{Ml} are the maximum simulated and observed values at site l.
Fractional bias	$\left(\frac{1}{N}\right)\sum_{l=1}^{N}(S_l - O_l)/0.5(S_l + O_l)$
Fractional gross error	$\left(\frac{1}{N}\right)\sum_{l=1}^{N}\lvert S_l - O_l\rvert/0.5(S_l + O_l)$
Mean residual (ppb)	$\left(\frac{1}{N}\right)\sum_{l=1}^{N}(S_l - O_l)$
Root mean square error (ppb)	$\sqrt{\left(\frac{1}{N}\right)\sum_{l=1}^{N}(S_l} - O_l)^2$

Daily maximum 8-hour ozone concentrations for Grid 1 were also examined. The isopleth patterns (not shown) look similar to those in the 1-hour plots; the extent and/or value of the similarly labeled isopleths, however, are reduced. The location of the maximum value for each day remains roughly the same throughout the simulation and only changes clearly for the last day. The difference between the simulated 1-hour peak value and the simulated 8-hour peak value keeps steadily between 10-20 ppb throughout the simulation.

Metrics characterizing the 8-hour ozone concentrations for Grid 1 are provided in Table 6-6a. A threshold value of 40 ppb was also used for the calculation of the 8-hour relative statistics. Statistics for 8-hour ozone are generally very similar to the 1-hour ozone statistics. For that reason, only the maximum and average observed and simulated values are displayed. The maximum simulated 8-hr ozone concentration is lower than the observed peak for days 16, 18 and 19, and higher than the observed peak for all other days. The mean simulated value (averaged over all monitoring sites) is lower than the mean observed value for all but the last simulation day, suggesting some regional-scale underestimation of ozone concentrations for this episode period.

Grid 2 Subdomain

For this subdomain, graphical and statistical analysis of the simulation results was used to assess model performance with respect to the spatial and temporal distribution of ozone and subdomain-wide and site-specific peaks. The Grid 2 subdomain provides a more detailed picture of the ozone plumes between South Carolina and the surrounding areas.

Daily maximum simulated ozone concentration plots for Grid 2 for each simulation day for the May 1998 modeling episode period are presented in Figure 6-2. The maximum simulated 1-hour ozone concentrations for this subdomain are located within and downwind of the Atlanta area or within or offshore of South Carolina for the majority of the simulation days. As noted in Section 4, regional-scale wind directions varied throughout the simulation period over this part of the domain and this affects the ozone concentration patterns. Southwesterly to westerly winds during 18-20 May are associated with apparent transport of ozone (in the simulation) from the Atlanta metropolitan area toward western South Carolina. Comparison with observed maximum values indicates that the model performs well throughout the simulation at most of the sites. There is some underestimation of the peak ozone values at some Georgia, North Carolina and South Carolina sites for 18-19 May. Model performance for these areas is examined in more detail later in this section. The maximum 1-hour value for this simulation is 149.6 ppb at Atlanta on May 19.

Table 6-5b shows selected metrics and statistics for 1-hour ozone for Grid 2. The simulated maximum ozone concentration is greater than the observed maximum value for all days, with the exception of 16 May, but the difference is within 5-10 ppb. Notice that comparing domain-wide simulated and observed peaks may not be an accurate representation of model performance, due to the lack of a homogeneous network of monitoring stations. However, it gives a good general picture of the performance relative to the peak with respect to the existing monitors, which are mostly placed around urban areas. The mean simulated value is lower than the mean observed value for days 16 through 22 May, but again the difference is within 5-10 ppb for most days, indicating good performance on average. The unpaired accuracy of the peak shows that the peak anywhere in the domain is typically higher than observed. The average accuracy of the peak is a better measure of the simulation performance at the monitoring stations, as is the normalized bias. Both of these measures indicate underestimation of observed values for 18 and 19 May, overestimation of the observed values for 23 May, and good performance for the remaining days. For all days, the normalized gross error is within the EPA recommended range. Overall, these statistical measures show good performance of the model for the Grid 2 domain, with underestimation of the observed data at the monitoring sites on 18 and 19 May, and to a lesser extent on 20 May. With the exception of the unpaired accuracy of the (domain-wide) peak, all statistical measures are within the EPA recommended ranges for acceptable model performance.

The 8-hour ozone concentration patterns are similar to the 1-hour patterns. The domain-wide 8-hour peak simulated values are located around the same areas than the 1-hour peak values for days 16-22. The maximum 8-hour simulated value for this subdomain for any day is 123.7 ppb on 20 May, located to the east of the Atlanta area, close to the border with South Carolina.

Table 6-6b provides summary metrics for 8-hour ozone for Grid 2. The maximum simulated 8-hour ozone concentration is higher than the observed value for most days. The mean simulated value, however, is lower than the mean observed value for days 16 through 21, and higher than the mean observed value for 22 and 23 May, following the same tendencies noted for 1-hour ozone.

South Carolina Subdomain (Grid 3)

A detailed and comprehensive evaluation of model performance was conducted for Grid 3, with emphasis on the 1-hour and 8-hour ozone spatial concentration patterns and day-to-day differences, as well as site-specific model performance in the South Carolina area. The Grid 3 domain encloses South Carolina and the neighboring areas of Georgia and North Carolina.

Figure 6-3 provides plots of daily maximum simulated 1-hour ozone concentration for Grid 3 for each simulation day. The isopleth plots show a build-up of ozone during the first two simulation days (the start-up days). Beyond that, the simulated concentrations over South Carolina remain about the same (with maximum values on the order of 80 to 100 ppb), but the areas of high and low simulated ozone (the concentration pattern) varies from day to day. For the Columbia area, the relatively high maximum ozone values that were observed for 19 through 22 May (90 ppb and above) are generally represented by simulated values of 80 to greater than 100 ppb. In the northwest portion of the state (the Greenville-Spartanburg area), the maximum concentrations are underestimated for most days and sites. In the Aiken (Augusta) area, the high observed ozone concentrations (100 ppb and greater) are represented in the simulation but the isopleths do not always encompass the monitoring sites with the higher values. In the Charleston area, the high maximum ozone values (e.g., for 21 and 22 May) are represented, but the gradient in ozone concentration, represented by lower ozone at the coast, is not captured by the model.

The simulation results also depict some possible transport patterns. Isopleths extend southward into South Carolina from the Charlotte area on the first several days of the simulation period, and eastward into South Carolina from the Atlanta area on several of the remaining days. In addition, there are ozone plumes extending offshore from South Carolina on 21 May and to a lesser extent on 22 May. The overall day-to-day variations in observed ozone concentration levels within the subdomain and the South Carolina areas of interest are generally well simulated, with some exceptions, including the generalized underestimation of the maximum ozone values during 18 through 20 May.

Time-series plots comparing the hourly simulated and observed ozone concentrations for all monitoring sites located within South Carolina are provided in Figure 6-4. In these plots, the square symbols represent the observed values, the solid line represents the simulated values (interpolated to the monitoring site location), and the shaded area represents the range of concentrations in the nine cells surrounding the grid cell in which the monitoring site is located. The time-series plots are organized by area of interest from roughly northwest to southeast, starting with the Anderson/Greenville/Spartanburg area. Subsequent plots depict simulated and observed concentrations for sites in the Rock Hill, Columbia/Aiken, Florence/Darlington, and Charleston areas. Plots for all days span two pages. In addition, time series plots for selected sites in Georgia (Atlanta and other areas) and North Carolina (Charlotte, Raleigh-Durham, and other areas) are presented in Figures 6-5 and 6-6, respectively.

For sites in the Anderson/Greenville/Spartanburg area (Figure 6-4a), the time-series plots show that the model captures the differences in diurnal concentration patterns between the more urban (e.g., Clemson) and rural (e.g., Long Creek sites). For some sites and days, sites, the plots illustrate a tendency of the model to underestimate the peak concentrations. For the Delta and N. Spartanburg sites, the nighttime ozone concentrations are overestimated, especially during the latter part of the simulation period, but the peaks tend be well represented for most days. Time-series plots for the two monitoring sites in the Rock Hill area are shown in Figure 6-4b. With the exception of some underestimation of the maximum ozone values for 18 and 19 May, the ozone concentration levels and patterns are well represented for the York and Chester sites.

Model performance varies across the Columbia and Aiken/Augusta areas, as shown in Figure 6-4c. For sites in the Aiken area, concentrations are underestimated for 18, 19, and to some extent 20 May, and then fairly well represented for the remainder of the period. Closer to Columbia, the diurnal concentration pattern observed for Congaree Swamp is not captured by the model. For the Parklane and Sandhill sites in the Columbia area, model performance is very good for all days.

The time-series plots indicate both over- and underestimation of the peak ozone values for the Indiantown and Pee Dee sites in the Florence/Darlington area (Figure 6-4d). Overestimation of ozone at both sites on 17 May is followed by underestimation of ozone at both sites for 18 through 20 May, and then very good performance for the remaining days.

Within the southern part of the state (Figure 6-4e), reasonable to good model performance is achieved for Ashton, an inland site, and the coastal, Charleston-area sites of Army Reserve and Bushy Park; some underestimation of ozone occurs at the Ashton site for 20 and 22 May. For the Cape Romain site, located along the coast to the north of Charleston, the relatively low observed ozone concentrations are generally overestimated, especially for 17 and 18 May. This suggests that the transition zone characterized by higher ozone offshore and lower ozone inland, which typically occurs along the coastline, may be shifted too far inland along this portion of the coastline. This is possibly due to a spatial or temporal shift in the development of the sea breeze. Without additional observations, it is not possible to confirm this.

Figure 6-5 presents time-series plots for sites in Grid 3 that are located in Georgia. The time-series plots for the Atlanta-area sites (Figure 6-5a) show good agreement between the simulated and observed values for most sites and days, but also some large underestimation of ozone for a couple of the sites for 19 May. Performance for most other sites located throughout the state (Figure 6-5b) is good for most days, with some underestimation of ozone for the Macon site but good to very good performance for Columbus- and Augusta-area sites.

Figure 6-6 presents time-series plots for selected sites in North Carolina that are also located in Grid 3. For the Charlotte area (Figure 6-6a), the simulation results show underestimation of the daytime ozone concentrations for the first part of the simulation period, followed by good to very good performance for the remaining days. Following a slow start in the Raleigh/Durham area (Figure 6-6b), good performance is achieved for most days and sites. Note that the simulation period begins on a day with relatively high ozone levels for this area, which, as is expected for a start up day, are underestimated.

Scatter plots, provided in Figure 6-7, also compare hourly simulated and observed concentrations. The coordinates of the points (asterisks) correspond to observed and simulated concentrations, for all monitoring sites and all hours. Points lined up along the x - y axis indicate good model performance. Those that fall under the x - y axis indicate underestimation of the observed concentrations, and those that fall above the axis indicate overestimation of the observed concentrations. For the May 1998 modeling episode period, the scatter plots are characterized by good agreement between the simulated and observed values, with a tendency for underestimation of the higher observed concentrations and some overestimation of the lower observed concentration, likely the nighttime observations. For the last day of the simulation, observations are generally overestimated. The worst agreement between the simulated and observed values is found for 23 May, and is mostly driven by the overestimation of lower observed concentrations and some overestimation of the high observed values at the monitoring sites.

Metrics and statistics for 1-hour ozone for Grid 3 are provided in Table 6-5c. The domain-wide peak is typically higher than observed (lower only for the first start-up day of the simulation). The mean simulated ozone is lower than the mean observed ozone for most of the days; the differences tend to be smaller during the latter part of the simulation period. The unpaired accuracy of the peak indicates that for all days the domain-wide simulated peak is similar to or greater than that observed at any site within the domain. The average accuracy parameter, consistently within the EPA recommended range, indicates generally good performance of the model in simulating the site-specific peak values, but with underestimation of the peaks for days 16-22 May. The normalized bias also indicates underestimation of the observed values greater than 40 ppb for 18 and 19 May. For all days, this parameter is also within or, for the last day, nearly within the EPA recommended range. The normalized gross error is also within EPA recommended ranges. In general, all these statistical measures indicate reasonable to good model performance for all days. For the last day, two of the model performance measures are just outside the EPA recommended ranges.

Plots of daily maximum 8-hour simulated ozone concentration for each simulation day are presented in Figure 6-8. The isopleth patterns are very similar to those for the 1-hour ozone concentration plots and the maximum location changes only for days 17 and 23 May. The maximum 8-hour simulated peak value for this domain is 123.7 ppb on May 20, located east of Atlanta, close to the border with South Carolina.

Metrics and statistics for 8-hour ozone for Grid 3 are provided in Table 6-6c. The simulated 8-hour domain-wide peak is greater than the observed peak for 17, 18, 20, 21, 22 and 23 May. The average simulated 8-hour ozone (averaged over all sites) is less than the average observed ozone on 18, 19 and 20 May, and greater than the observed value on the other days. The difference between the average simulated and observed maximum 8-hour ozone is not large, within 5-10 ppb for most days.

The main focus of this study is the evaluation of 8-hour ozone levels in the area covered by Grid 3. Thus, two additional statistics were calculated to provide a more detailed insight into the performance of the simulation for the 8-hour ozone levels. These new statistics describe the overall performance of the simulation for each day and for each monitoring site. The statistics were not calculated for the two first days or start-up days of the simulation because of the sensitivity of these days to the initial conditions of the simulation.

In Table 6-6d, the percent domain-wide accuracy of the peak and is equal to the sum, over all days in the simulation and monitoring sites in the domain, of the differences between the peak simulated and observed 8-hour ozone values, divided by the sum, over all monitoring sites, of the peak observed values. Per EPA guidance, the maximum simulated value for each site refers to the maximum value in the “vicinity” of the site location. For this modeling domain, vicinity is defined as the area within the 9 grid cells surrounding the site. This value describes the performance of the model in simulating maximum 8-hour ozone concentrations at sites located throughout the Grid 3 domain. EPA guidance offers a range of ±20 percent as an indicator of acceptable to good performance. The value is outside the EPA range only for the last day of the simulation, indicating that, on average, the simulation captures the site-specific 8-hour ozone peaks well. The domain-wide accuracy is negative for 18, 19 and 20 May, indicating underestimation of the 8-hour maximum values and positive but very small overestimation for 21 and 22 May. This measure was also computed using only data from sites in South Carolina. The values are slightly better when only South Carolina sites are considered. This comparison demonstrates that performance for South Carolina was generally consistent with that for all of Grid 3.

Table 6-6e shows the accuracy of the 9-cell 8-hour maximum ozone concentration calculated for each monitoring site within Grid 3 and over all non-start-up simulation days (18-23 May). The significance of this value is similar to that described above for the domain-wide accuracy, but it refers to the performance of the model (on average) for each monitoring station over all the simulation days. The sites are listed in the table by area of interest, starting with the Atlanta area in Georgia, followed by the Charlotte and Raleigh/Durham areas in North Carolina, and finishing with areas of interest in South Carolina as follows: Anderson/Greenville/Spartanburg, Rock Hill, Columbia/Aiken, Florence/Darlington, and Charleston, in a similar way as the time series described earlier.

Looking at the site-specific values for accuracy, it is clear that the model performs well over most of the stations (accuracy within ±20 percent and for most stations within ±10 percent), but the performance is not indicated to be very good for the Delta monitoring site in the Anderson/Greenville/Spartanburg area nor for the Cape Romain monitoring site along the South Carolina coast. For both sites the model overestimates the 8-hour ozone levels. For the Delta site, this occurs as a result of overestimation of the nighttime values. For the Cape Romain site, it is mostly the daytime values that are overestimated. Performance at all other sites is fairly good. For most sites, the values are negative, indicating some underestimation, on average, of the observed values at the sites.

Key Findings from the Base-Case Modeling Analysis

The base-case modeling analysis results indicate that the MM5/UAM-V modeling system can be used to successfully simulate the ozone concentration levels and patterns that occurred within South Carolina during the unique processes leading to high ozone along South Carolina. Key findings related to model performance include:

- Model performance varies by day, and within sub-regions
- Statistical measures for all domains (Grids 1, 2 and 3) are generally within the EPA recommended ranges
- There is no consistent bias toward over- or underestimation (1-hour and 8-hour) on a domain-wide or site-specific basis. However, observed peaks are underestimated at many sites for 18-20 May. The reason may be that precursor emissions (CO and VOC emissions) from wildfires in Central America influenced the ozone levels on these days but are not represented in the simulation. Diagnostics analysis seems to support this theory.
- Changes to the UAM-V inputs (emissions, meteorological, initial and boundary conditions) produce expected (and moderate) responses
- Model performance for South Carolina is consistent with that for Georgia and North Carolina, which indicates that the modeling emission inventories developed for the first time for South Carolina are of comparable quality to those for the neighboring states, which have been used and refined extensively for the purposes of air quality modeling.

Based on a review of these results, the Technical Work Group determined that the base-case modeling was acceptable. The meteorological and other inputs developed as part of the base-case modeling effort were used for future year modeling, as described in the following section.

Table 6-5a
Summary of model performance metrics and statistics for 1-hour ozone for the 36 km UAM-V modeling domain (Grid 1): base-case simulation. Shading indicates that the calculated statistical measure is outside the EPA recommended range for acceptable model performance.

Simulation Day	Maximum Observed Ozone (ppb)	Maximum Simulated Ozone (ppb)	Mean Observed Ozone (ppb)	Mean Simulated Ozone (ppb)	Unpaired Accuracy of the Peak (%)	Average Accuracy of the Peak (%)	Normalized Bias (%)	Normalized Gross Error (%)	RMS Error (ppb)
980516	123	117.0	64.0	48.8	-4.9	-12.0	-21.0	32.0	27.7
980517	118	127.9	63.1	55.5	8.4	-11.7	-10.6	20.7	15.9
980518	124	130.8	68.9	58.1	-17.8	-14.8	-13.3	21.9	18.9
980519	146	149.6	73.5	64.0	2.5	-14.0	-11.0	19.0	17.5
980520	137	143.3	71.0	62.1	4.6	-15.6	-9.4	20.8	18.8
980521	120	129.8	66.1	62.6	-3.9	-4.4	-2.5	18.1	14.5
980522	132	132.5	59.2	55.5	0.4	-1.7	-3.7	20.2	15.2
980523	98	118.3	53.0	55.7	-3.8	8.3	6.7	20.1	13.2

Table 6-5b
Summary of model performance metrics and statistics for 1-hour ozone for the 12 km UAM-V modeling domain (Grid 2): base-case simulation. Shading indicates that the calculated statistical measure is outside the EPA recommended range for acceptable model performance.

Simulation Day	Maximum Observed Ozone (ppb)	Maximum Simulated Ozone (ppb)	Mean Observed Ozone (ppb)	Mean Simulated Ozone (ppb)	Unpaired Accuracy of the Peak (%)	Average Accuracy of the Peak (%)	Normalized Bias (%)	Normalized Gross Error (%)	RMS Error (ppb)
980516	123	117.0	65.2	54.8	-4.9	-5.8	-13.1	26.9	22.0
980517	118	127.9	62.6	57.4	8.4	-8.7	-6.3	20.6	15.9
980518	124	130.8	70.2	58.4	5.4	-15.6	-14.4	22.3	19.2
980519	146	149.6	76.4	64.2	2.5	-17.0	-13.7	19.8	18.6
980520	137	143.3	72.4	65.2	4.6	-12.9	-6.9	19.2	17.6
980521	120	129.8	68.3	64.8	8.1	-6.2	-3.0	16.3	13.7
980522	132	132.5	59.1	58.0	0.4	-1.3	0.3	19.2	13.9
980523	98	118.3	53.5	59.7	20.7	13.4	13.3	20.9	13.8

Table 6-5c
Summary of model performance metrics and statistics for 1-hour ozone for the 4 km SCDHEC UAM-V modeling subdomain (Grid 3): base-case simulation. Shading indicates that the calculated statistical measure is outside the EPA recommended range for acceptable model performance.

Simulation Day	Maximum Observed Ozone (ppb)	Maximum Simulated Ozone (ppb)	Mean Observed Ozone (ppb)	Mean Simulated Ozone (ppb)	Unpaired Accuracy of the Peak (%)	Average Accuracy of the Peak (%)	Normalized Bias (%)	Normalized Gross Error (%)	RMS Error (ppb)
980516	123	117.0	65.5	57.6	-4.9	-5.4	-8.7	23.8	19.6
980517	118	127.9	62.9	60.6	8.4	-4.8	-0.7	22.3	17.1
980518	124	130.8	71.6	59.3	5.4	-16.0	-14.1	23.0	20.0
980519	146	149.6	76.7	63.7	2.5	-16.9	-14.6	20.9	19.7
980520	122	143.3	74.5	66.9	17.5	-12.1	-7.5	18.7	17.0
980521	116	129.8	69.3	66.6	11.9	-6.4	-1.6	15.8	13.1
980522	132	132.5	61.7	60.6	0.4	-2.3	1.1	20.1	14.9
980523	98	118.3	55.7	63.2	20.7	15.1	15.8	21.7	14.7

Table 6-6a
Summary of model performance metrics and statistics for 8-hour ozone for the 36 km UAM-V modeling domain (Grid 1): base-case simulation.

Simulation Day	Maximum Observed Ozone (ppb)	Maximum Simulated Ozone (ppb)	Mean Observed Ozone (ppb)	Mean Simulated Ozone (ppb)
980516	107.6	98.4	61.7	48.5
980517	96.4	110.0	60.8	55.9
980518	123.5	116.5	65.2	57.5
980519	125.1	122.2	71.3	64.0
980520	122.8	123.7	69.4	62.4
980521	107.3	114.6	64.4	63.2
980522	103.9	112.5	57.9	56.1
980523	88.3	107.8	51.8	56.2

Table 6-6b
Summary of model performance metrics and statistics for 8-hour ozone for the 12 km UAM-V modeling domain (Grid 2): base-case simulation.

Simulation Day	Maximum Observed Ozone (ppb)	Maximum Simulated Ozone (ppb)	Mean Observed Ozone (ppb)	Mean Simulated Ozone (ppb)
980516	107.6	98.4	62.6	53.7
980517	96.4	110.0	60.4	57.7
980518	110.8	116.5	66.5	57.5
980519	125.1	122.2	74.0	63.8
980520	116.6	123.7	71.0	65.4
980521	104.3	114.6	66.7	65.3
980522	103.9	112.5	57.4	58.5
980523	76.8	107.8	51.9	59.6

Table 6-6c
Summary of model performance metrics and statistics for 8-hour ozone for the 4 km SDCHEC UAM-V modeling subdomain (Grid 3): base-case simulation.

Simulation Day	Maximum Observed Ozone (ppb)	Maximum Simulated Ozone (ppb)	Mean Observed Ozone (ppb)	Mean Simulated Ozone (ppb)
980516	107.6	98.4	62.7	56.7
980517	96.4	110.0	61.0	60.6
980518	108.6	116.5	68.3	58.0
980519	125.1	122.2	74.6	63.5
980520	105.8	123.7	73.1	67.1
980521	104.3	114.6	68.1	67.4
980522	103.9	112.5	59.6	60.9
980523	76.8	107.8	53.9	63.3

Table 6-6d
Average accuracy of the simulation over selected monitoring stations in Grid 3 (Cutoff = 40 ppb).

Day	Peak 8hr 9-cells Sim
18	-8.0
19	-13.0
20	-8.0
21	1.0
22	3.0
23	22.0

Table 6-6e
Site-specific average accuracy of the 8-hour peak ozone concentration (%) for selected sites in Grid 3.

Site	9-Cell Site-Specific Average Accuracy of the 8-Hour Ozone Peak (%)
Atlanta Area - GA	
Dawson Co., GA	14.4
Dawsonville, GA	14.4
So. Dekalb, GA	?
Tucker, GA	-5.2
Douglasville, GA	-5.3
Fannin Co., GA	-0.4
Fayetteville, GA	-6.9
Confederate, GA	-14.7
Lawrenceville, GA	-6.0
Yorkville, GA	-3.1
Conyers, GA	-8.0
Charlotte Area - NC	
Charlotte Lakedell, NC	-13.1
Mecklenburg Cty, NC	-8.7
Mecklenburg Cab C, NC	-16.2
Raleigh-Durham Area - NC	
Durham, NC	-2.5
Wake Cty, NC	-1.0
Raleigh, NC	-4.1
Fuquay-Varina, NC	-7.9
Garner, NC	-2.4
Anderson/Greenville/Spartanburg Area - SC	
Due West, SC	-2.8
Powdersville, SC	-10.5
Cowpens, SC	-9.0
Long Creek, SC	13.0
Clemson, SC	-2.9
North Spartanburg FS, SC	-6.8
Delta, SC	28.7
Rock Hill Area - SC	
Chester, SC	-11.7
York, SC	-7.7
Columbia Area - SC	
Parklane, SC	1.2
Sandhill, SC	-6.7
Congaree Swamp, SC	11.6
Aiken/Augusta Area - SC	
Jackson, SC	-3.7

Site	9-Cell Site-Specific Average Accuracy of the 8-Hour Ozone Peak (%)
Barnwell, SC	-9.2
Trenton, SC	-0.9
Augusta, GA	2.2
Florence/Darlington Area - SC	
Pee Dee, SC	-11.7
Indiantown, SC	4.5
Coastal Sites - SC	
Bushy Park, SC	4.2
Army Reserve, SC	9.1
Cape Romain, SC	59.2
Ashton, SC	-19.1

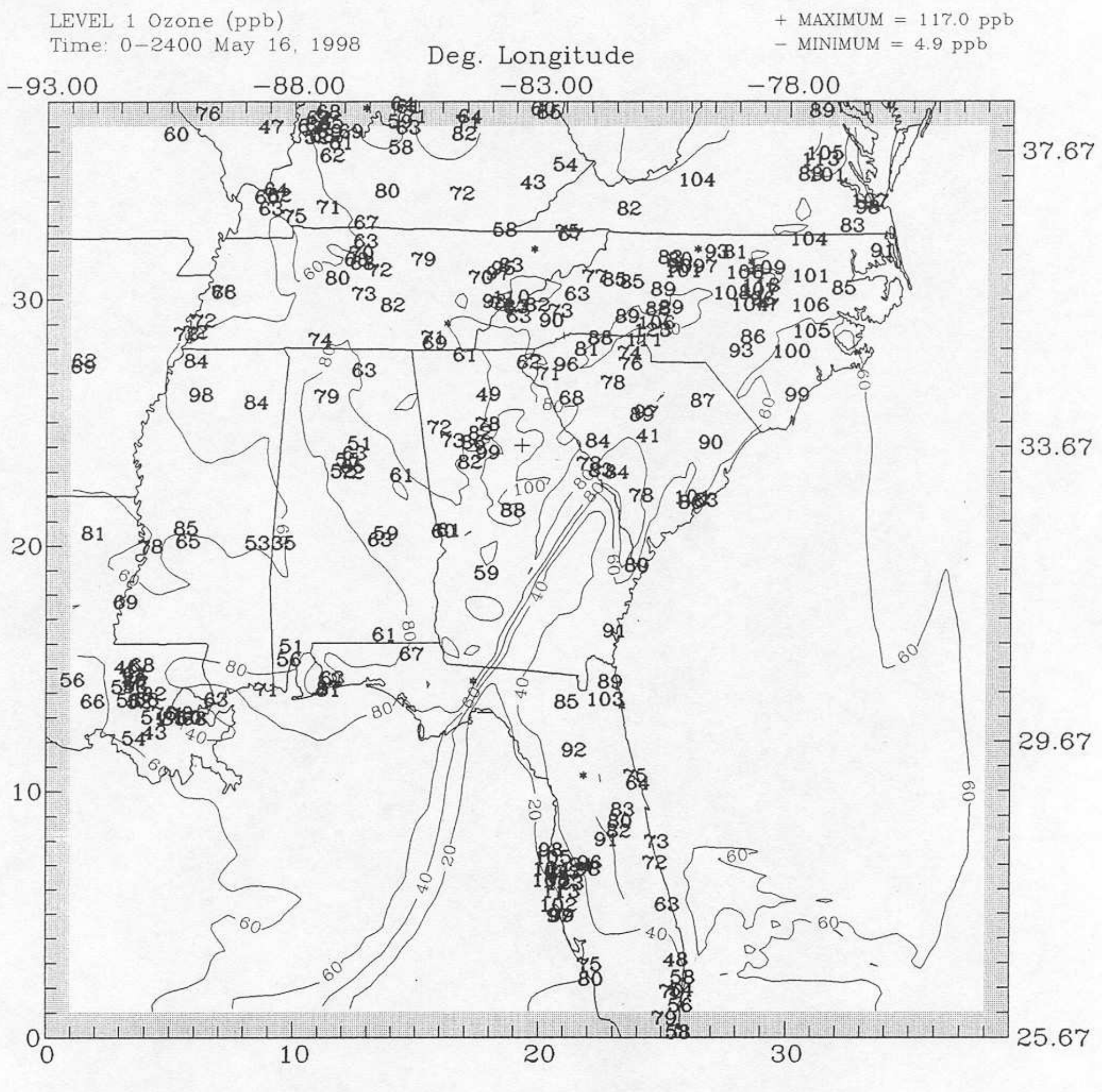

FIGURE 6−1a. Daily maximum UAM−V simulated 1−hour ozone concentration (ppb) for SCDHEC Grid 1: 16 May 1998. Observed values are shown in bold.

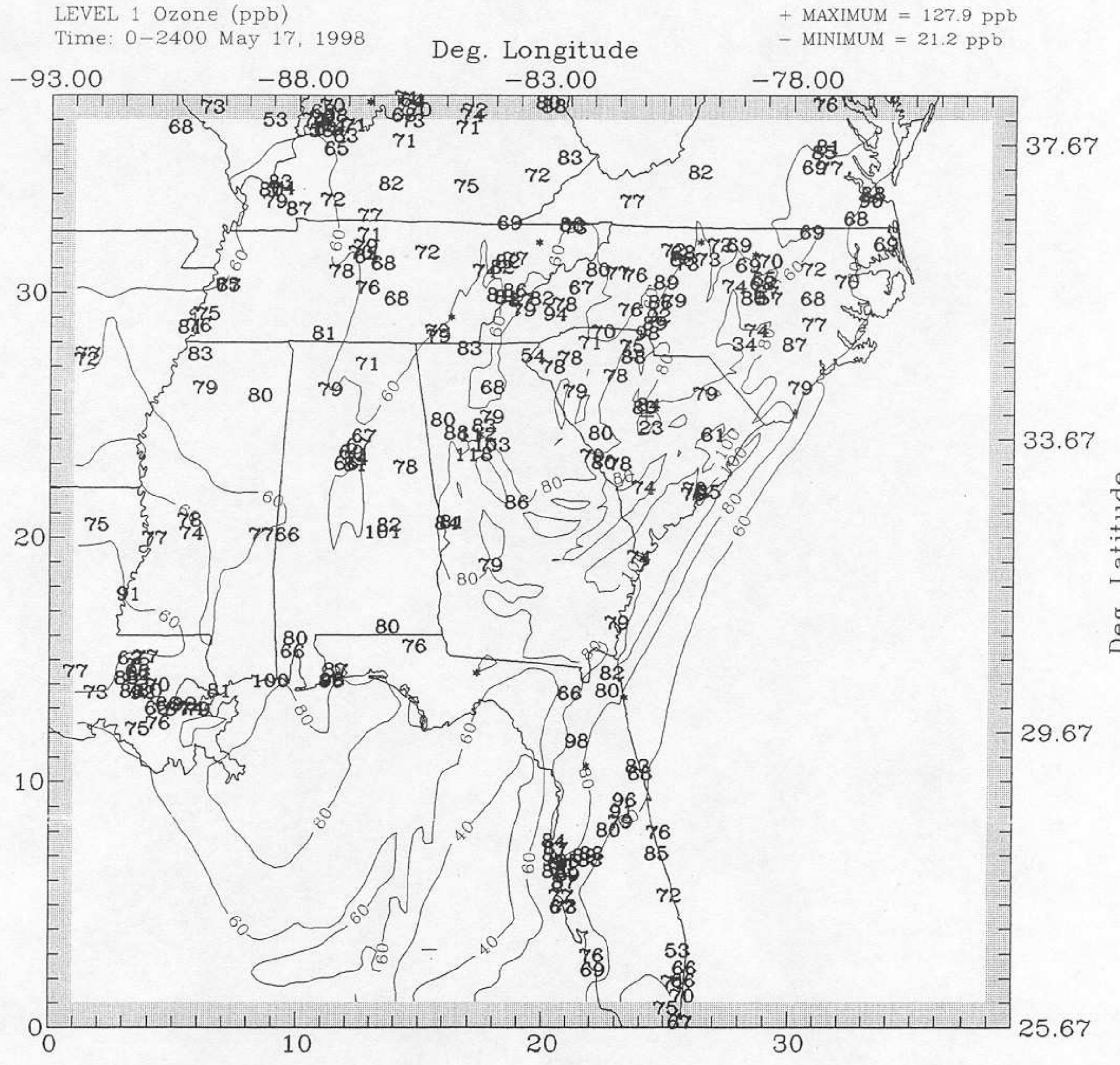

FIGURE 6-1b. Daily maximum UAM-V simulated 1-hour ozone concentration (ppb) for SCDHEC Grid 1: 17 May 1998. Observed values are shown in bold.

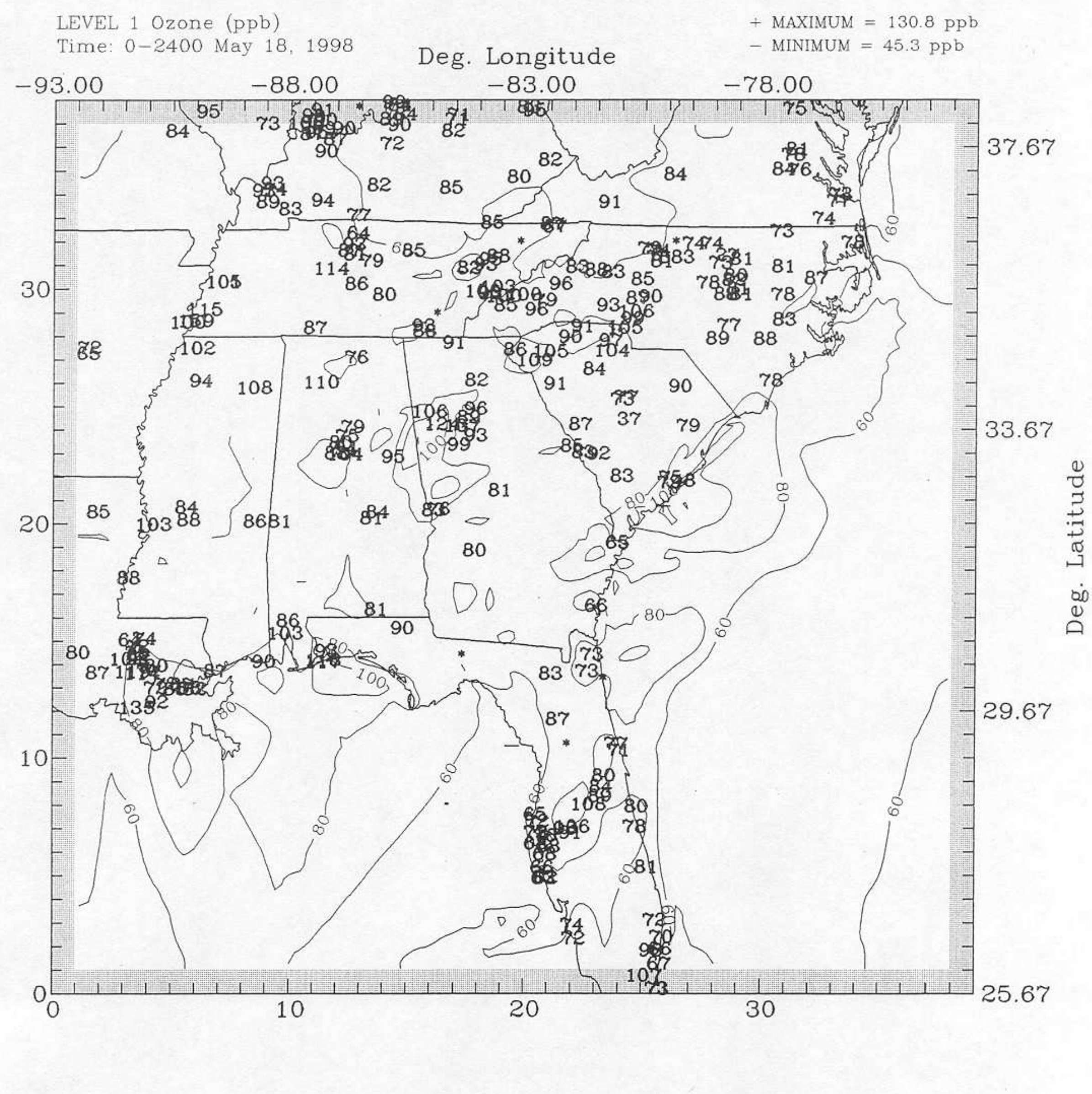

FIGURE 6-1c. Daily maximum UAM-V simulated 1-hour ozone concentration (ppb) for SCDHEC Grid 1: 18 May 1998. Observed values are shown in bold.

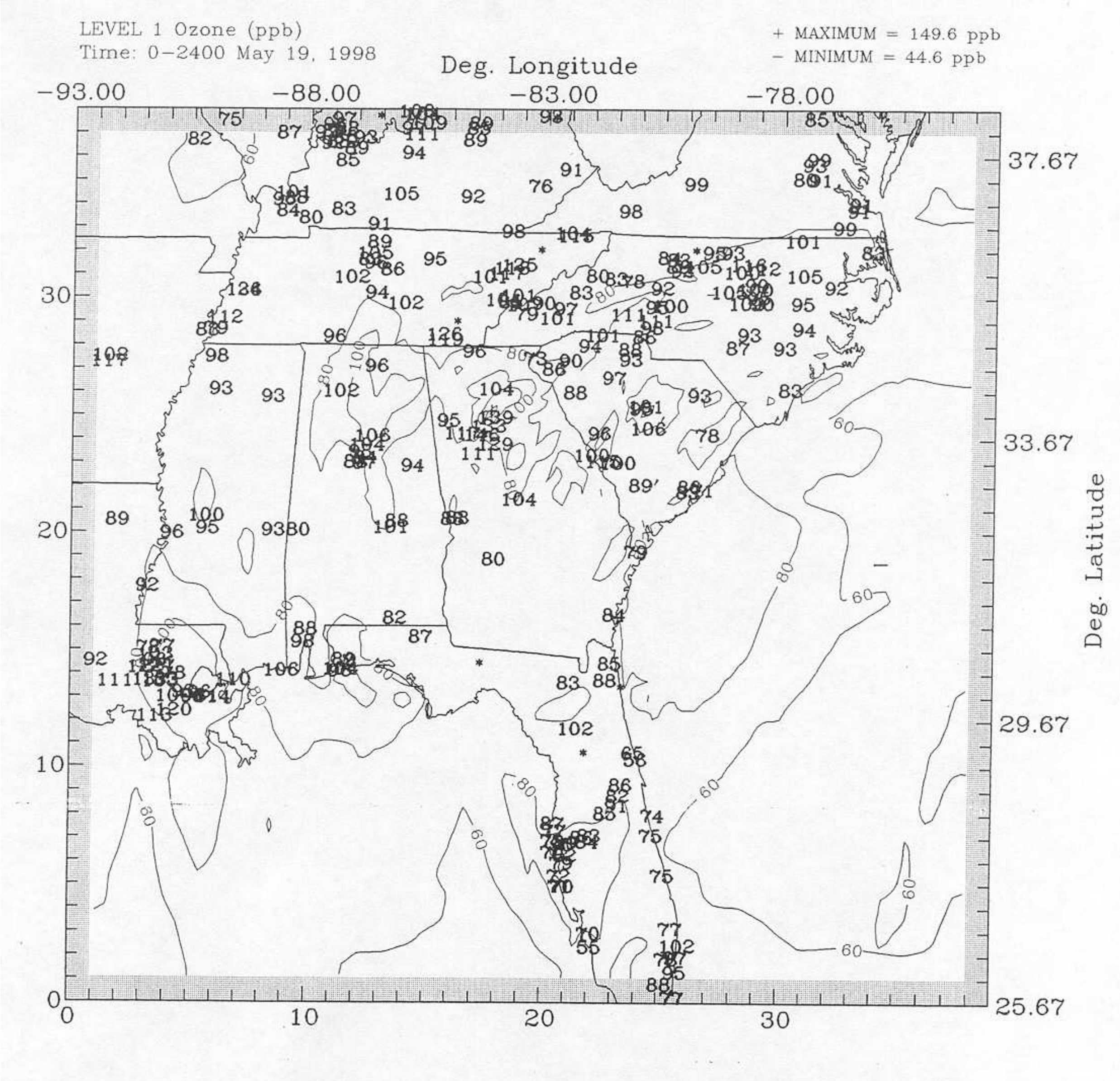

FIGURE 6−1d. Daily maximum UAM−V simulated 1−hour ozone concentration (ppb) for SCDHEC Grid 1: 19 May 1998. Observed values are shown in bold.

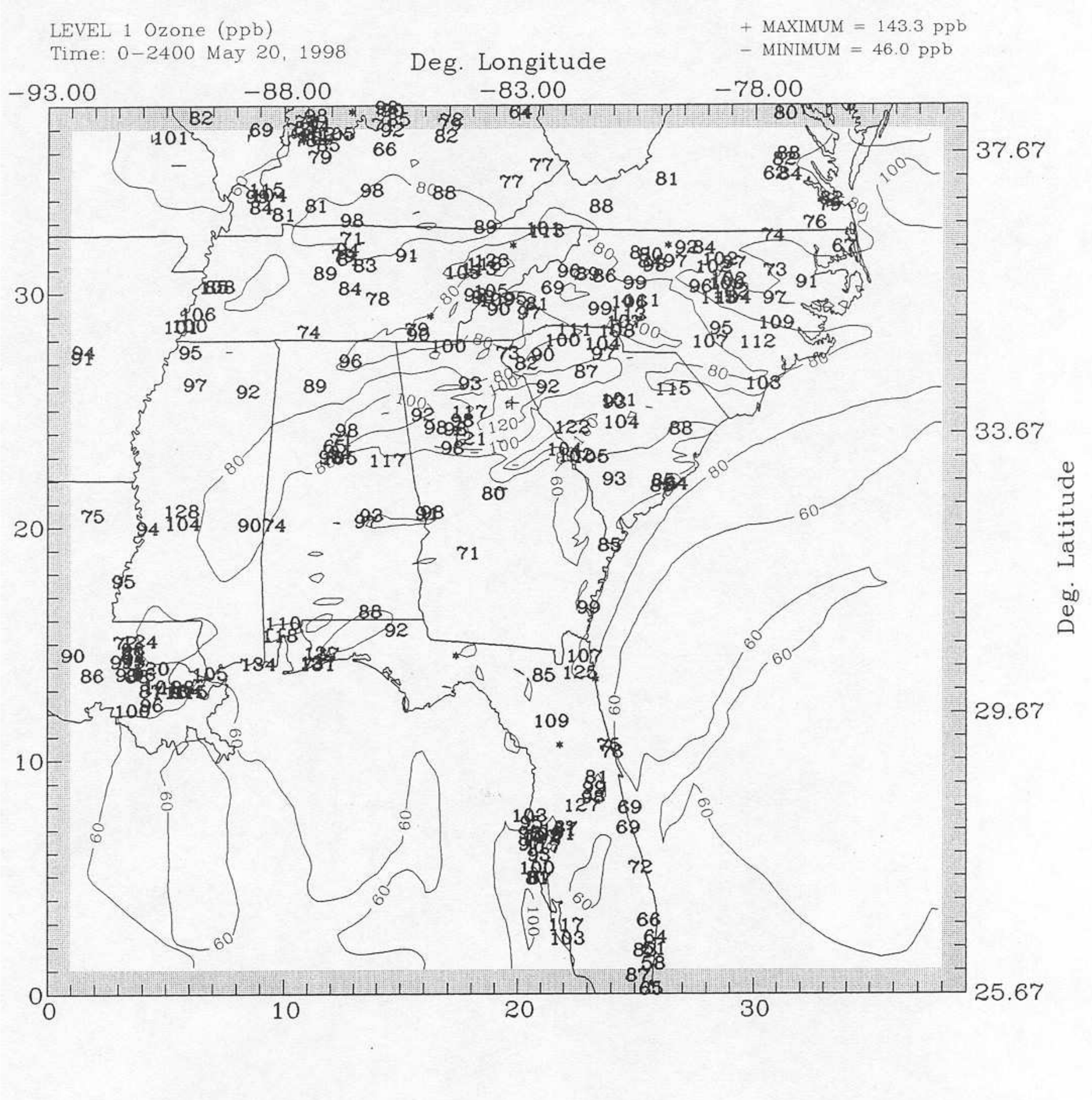

FIGURE 6−1e. Daily maximum UAM−V simulated 1−hour ozone concentration (ppb) for SCDHEC Grid 1: 20 May 1998. Observed values are shown in bold.

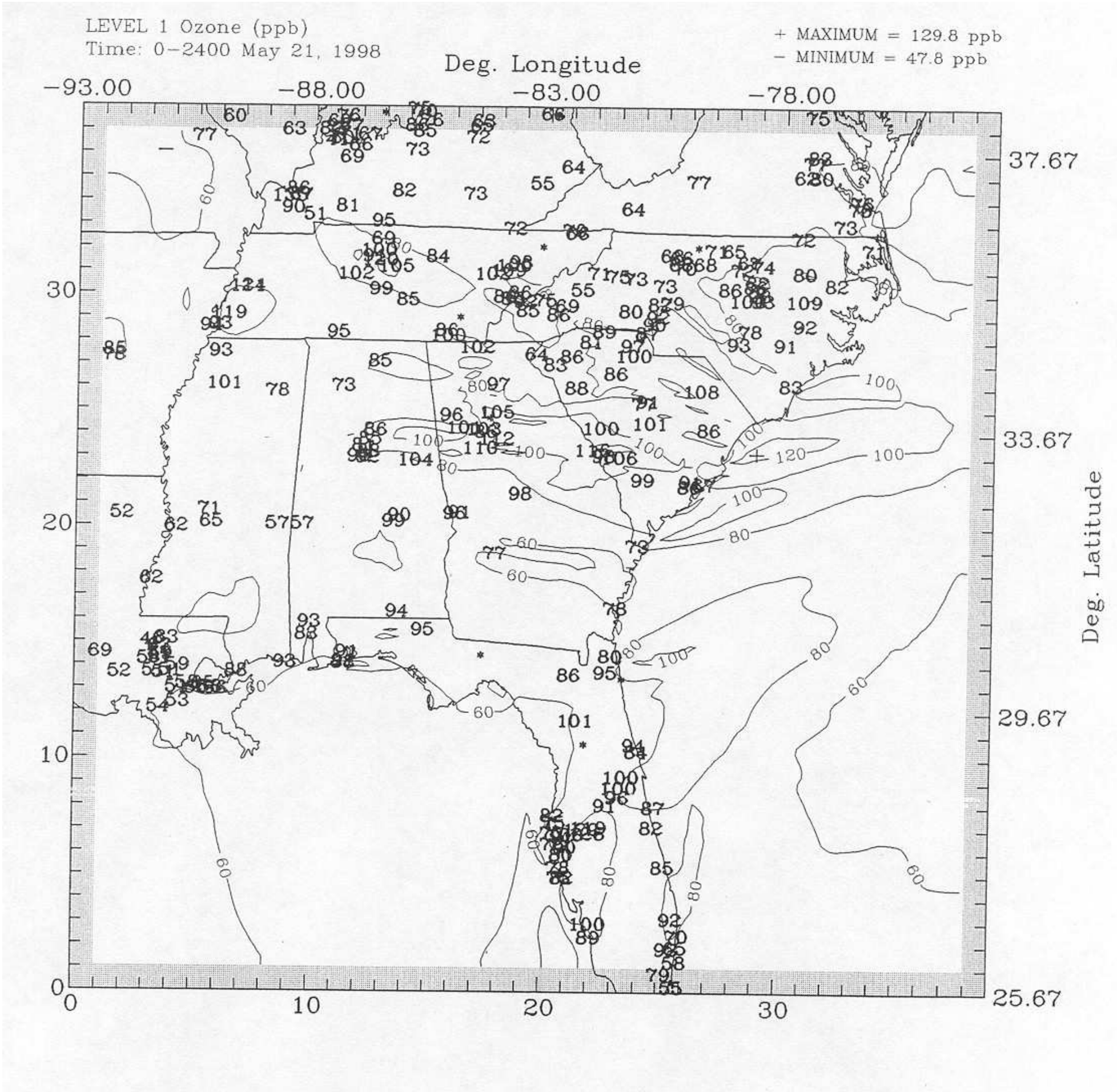

FIGURE 6-1f. Daily maximum UAM-V simulated 1-hour ozone concentration (ppb) for SCDHEC Grid 1: 21 May 1998. Observed values are shown in bold.

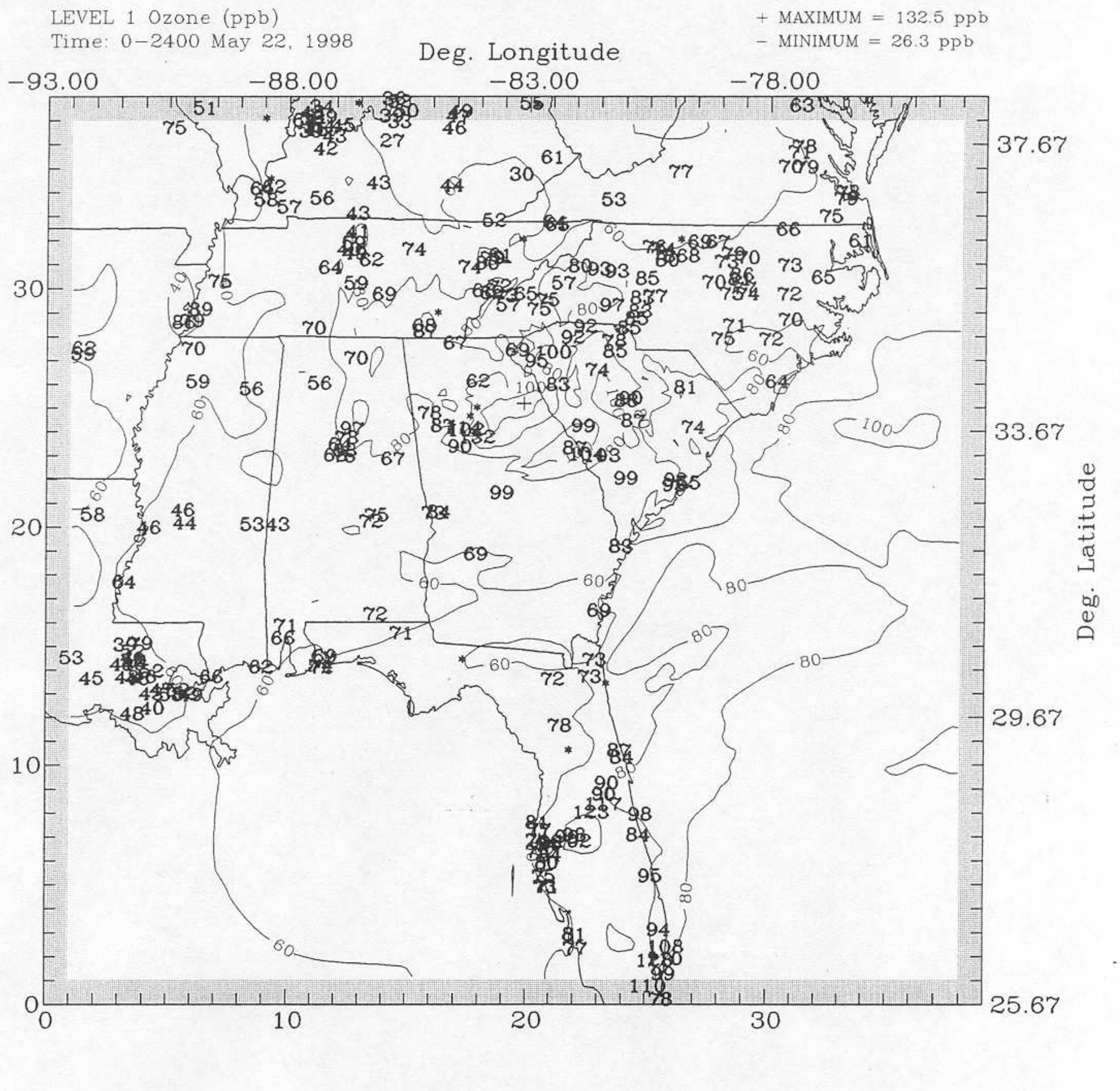

FIGURE 6-1g. Daily maximum UAM-V simulated 1-hour ozone concentration (ppb) for SCDHEC Grid 1: 22 May 1998. Observed values are shown in bold.

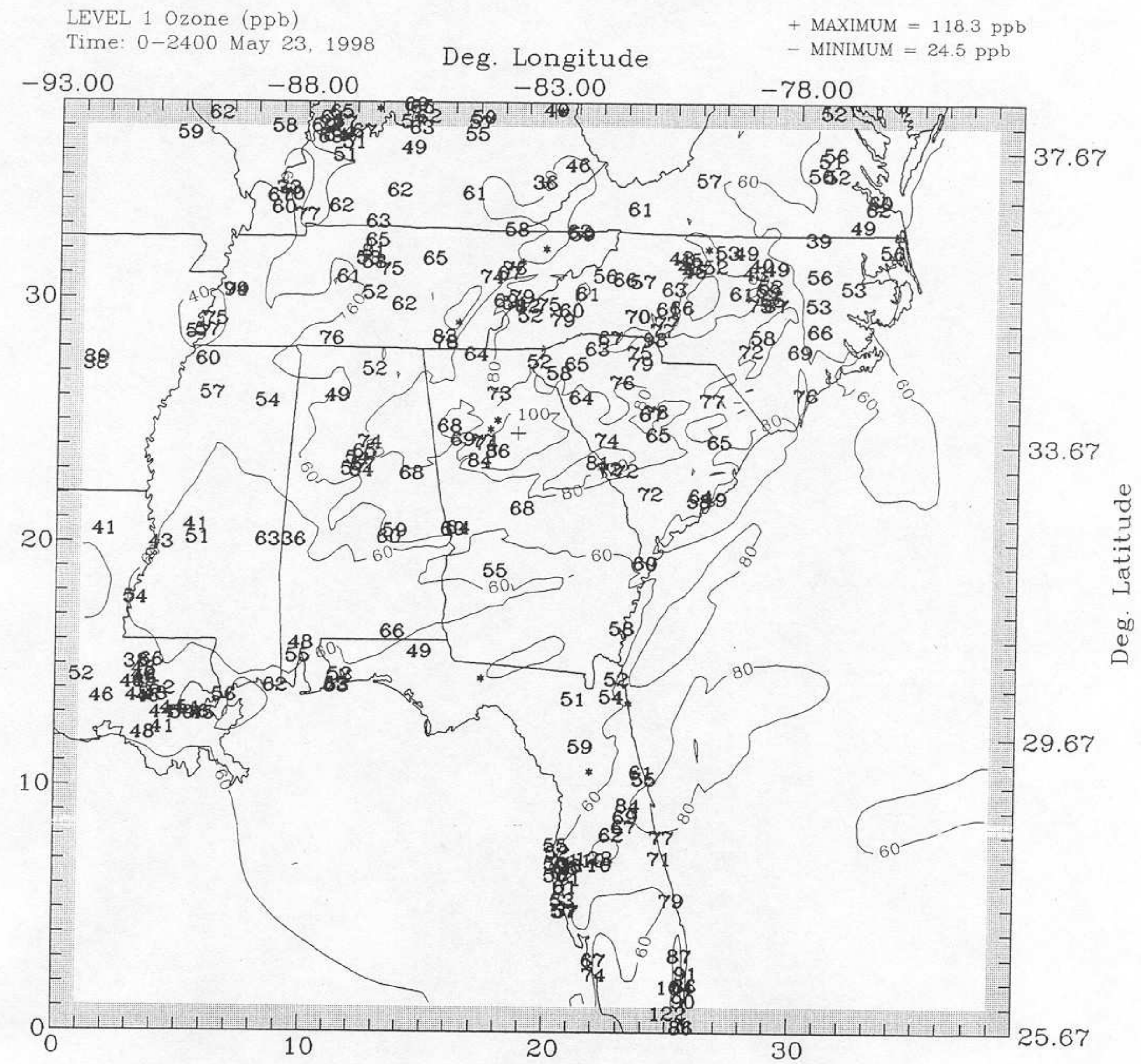

FIGURE 6−1h. Daily maximum UAM−V simulated 1−hour ozone concentration (ppb) for SCDHEC Grid 1: 23 May 1998. Observed values are shown in bold.

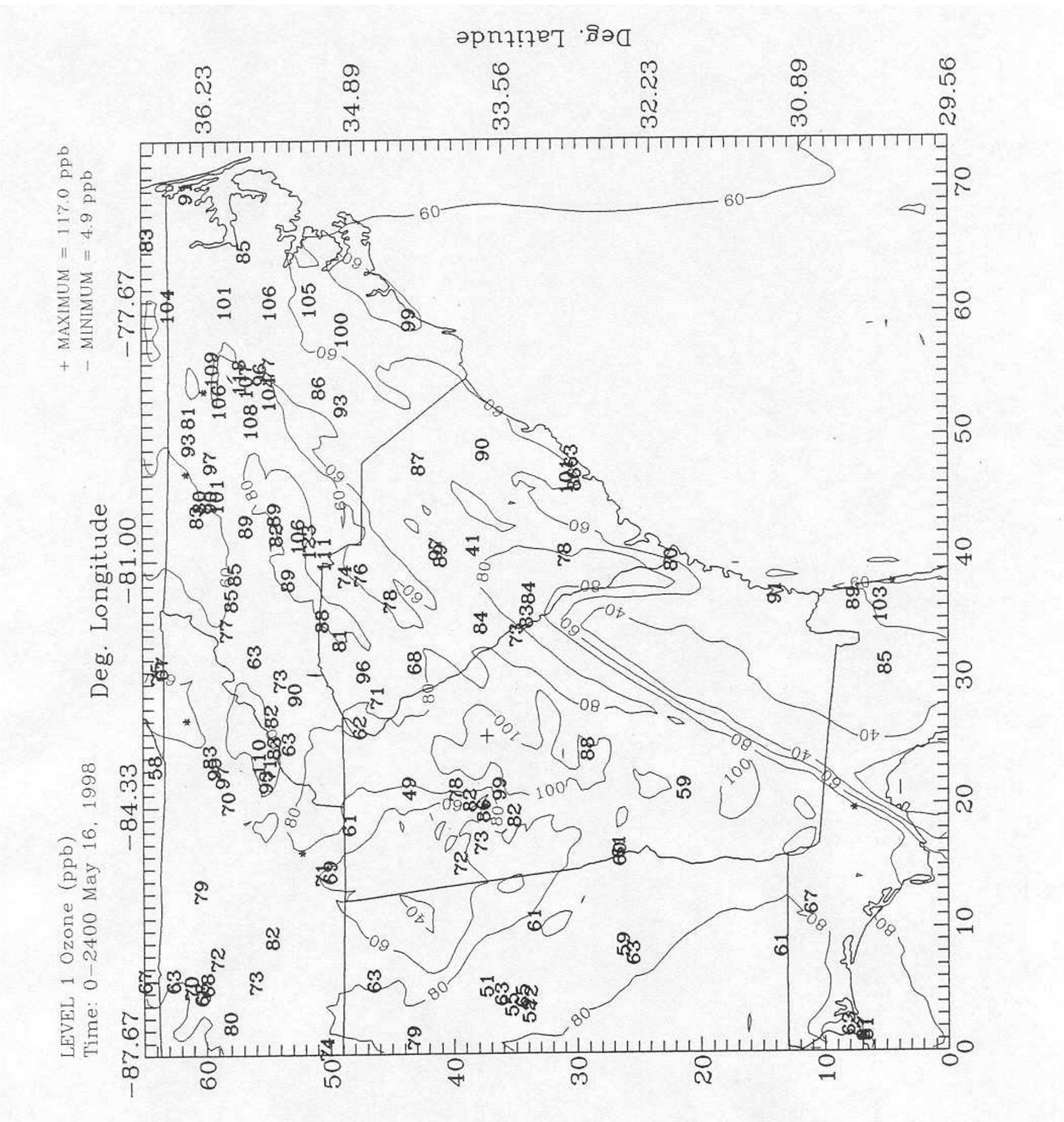

FIGURE 6-2a. Daily maximum UAM-V simulated 1-hour ozone concentration (ppb) for SCDHEC Grid 2: 16 May 1998. Observed values are shown in bold.

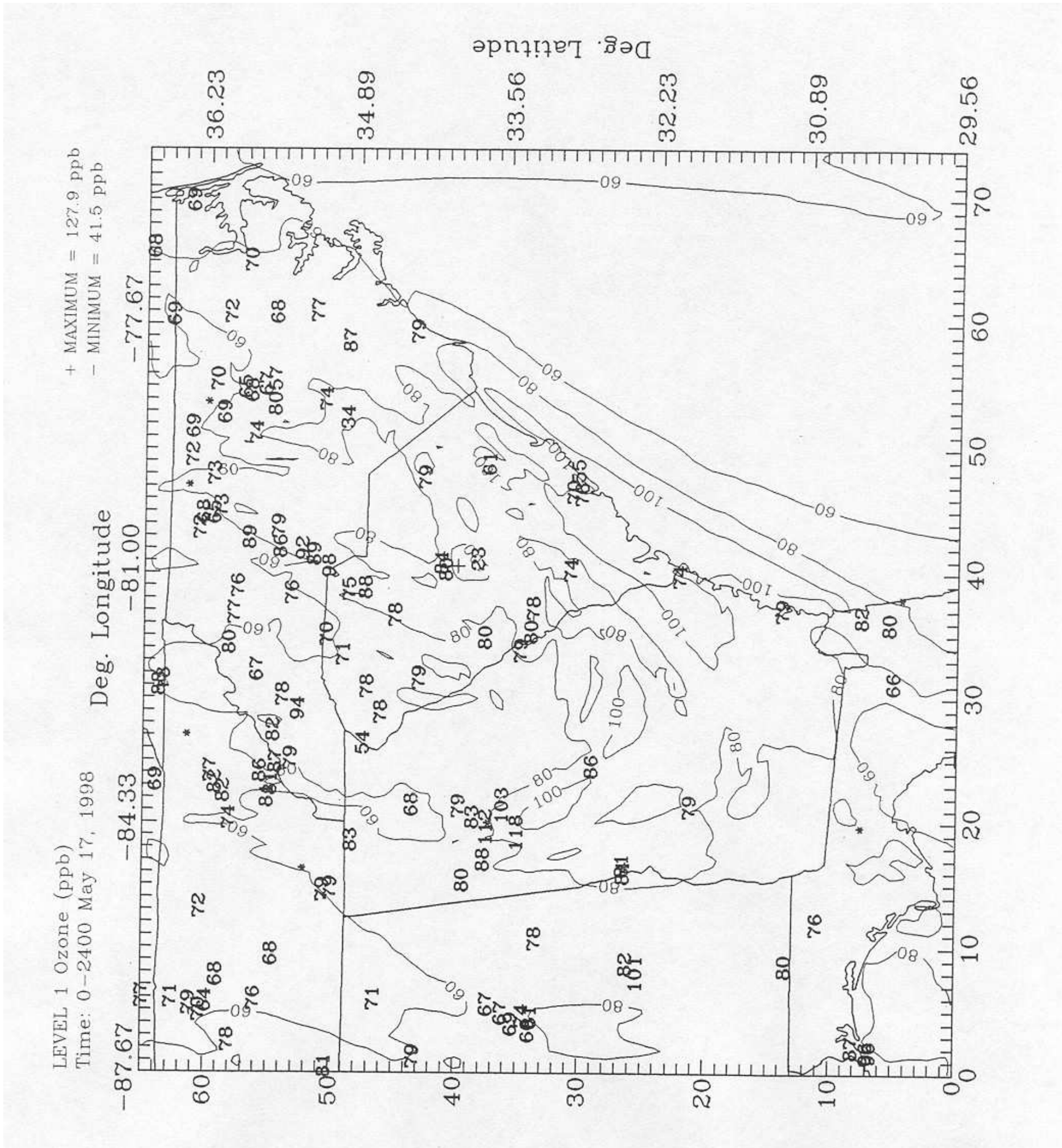

FIGURE 6-2b. Daily maximum UAM-V simulated 1-hour ozone concentration (ppb) for SCDHEC Grid 2: 17 May 1998. Observed values are shown in bold.

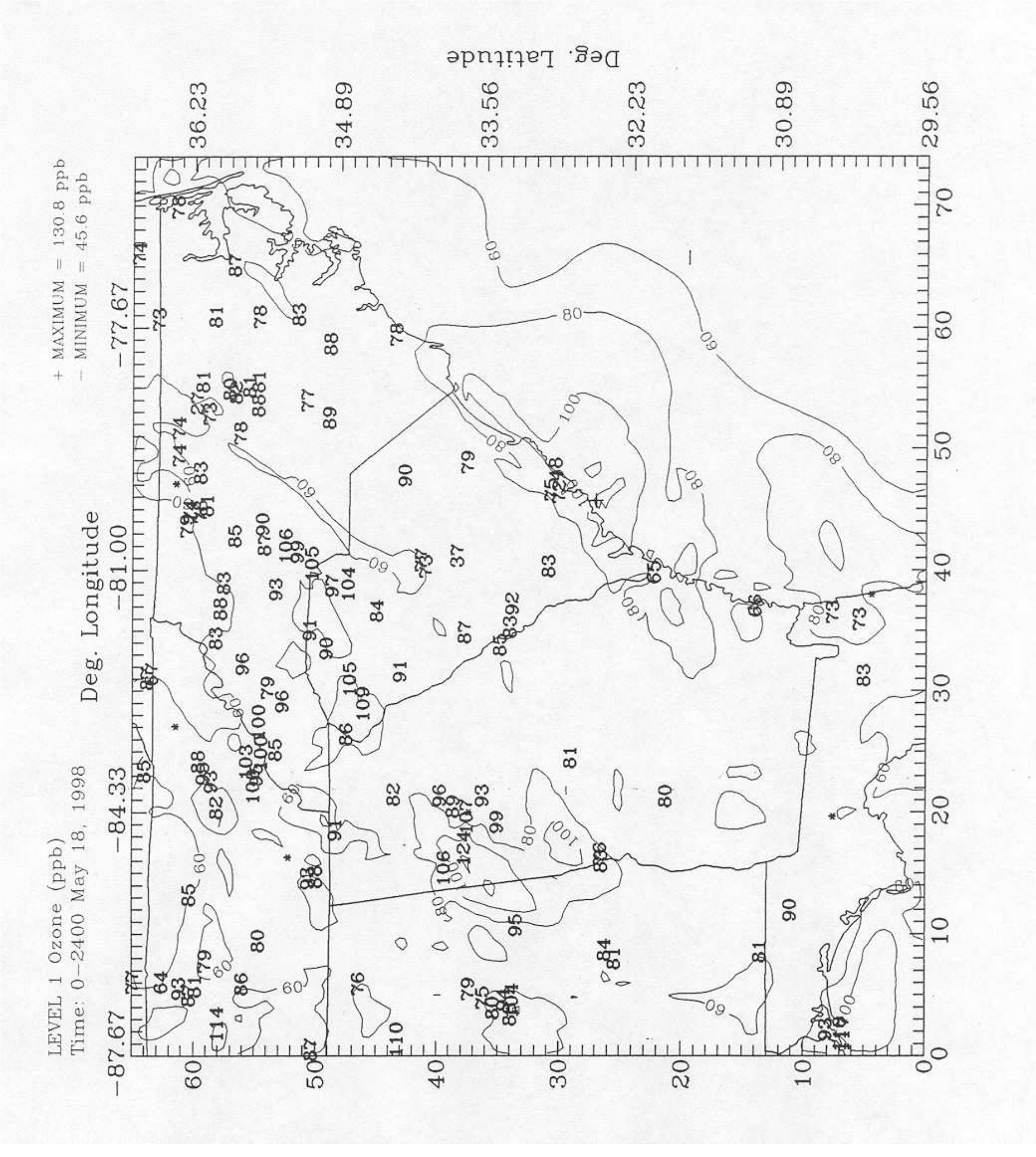

FIGURE 6-2c. Daily maximum UAM-V simulated 1-hour ozone concentration (ppb) for SCDHEC Grid 2: 18 May 1998. Observed values are shown in bold.

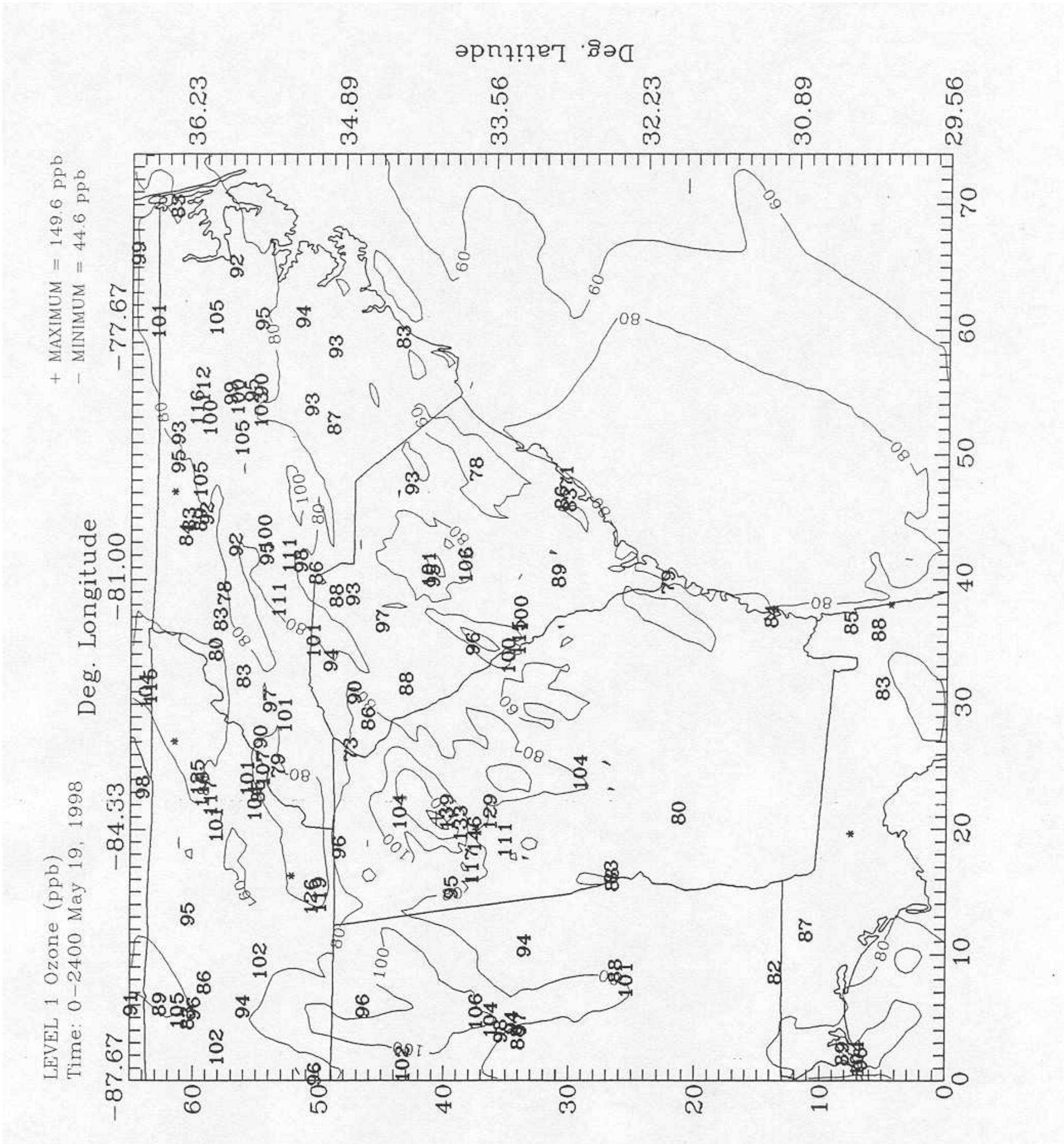

FIGURE 6–2d. Daily maximum UAM–V simulated 1–hour ozone concentration (ppb) for SCDHEC Grid 2: 19 May 1998. Observed values are shown in bold.

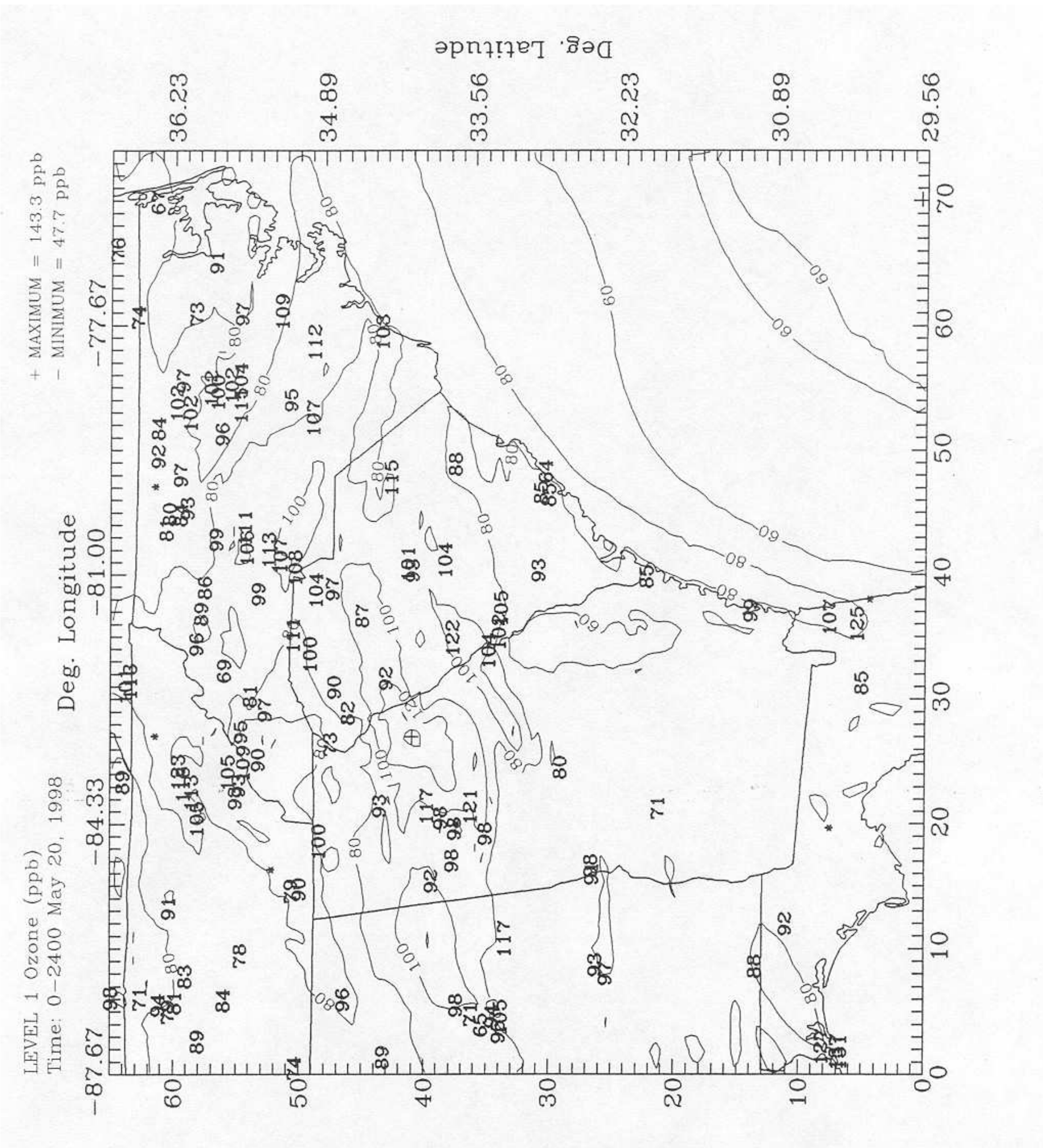

FIGURE 6-2e. Daily maximum UAM-V simulated 1-hour ozone concentration (ppb) for SCDHEC Grid 2: 20 May 1998. Observed values are shown in bold.

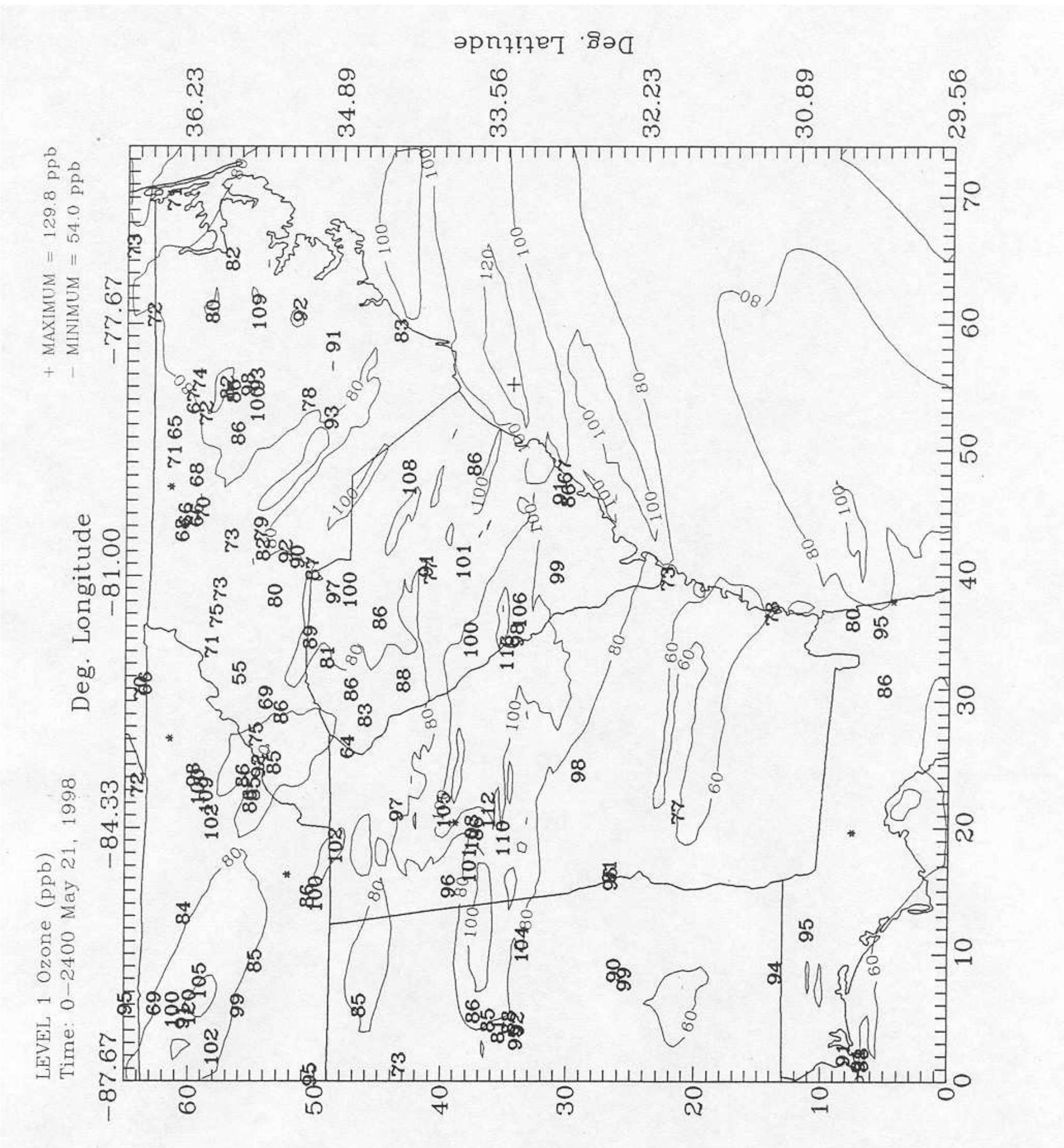

FIGURE 6-2f, Daily maximum UAM-V simulated 1-hour ozone concentration (ppb) for SCDHEC Grid 2: 21 May 1998. Observed values are shown in bold.

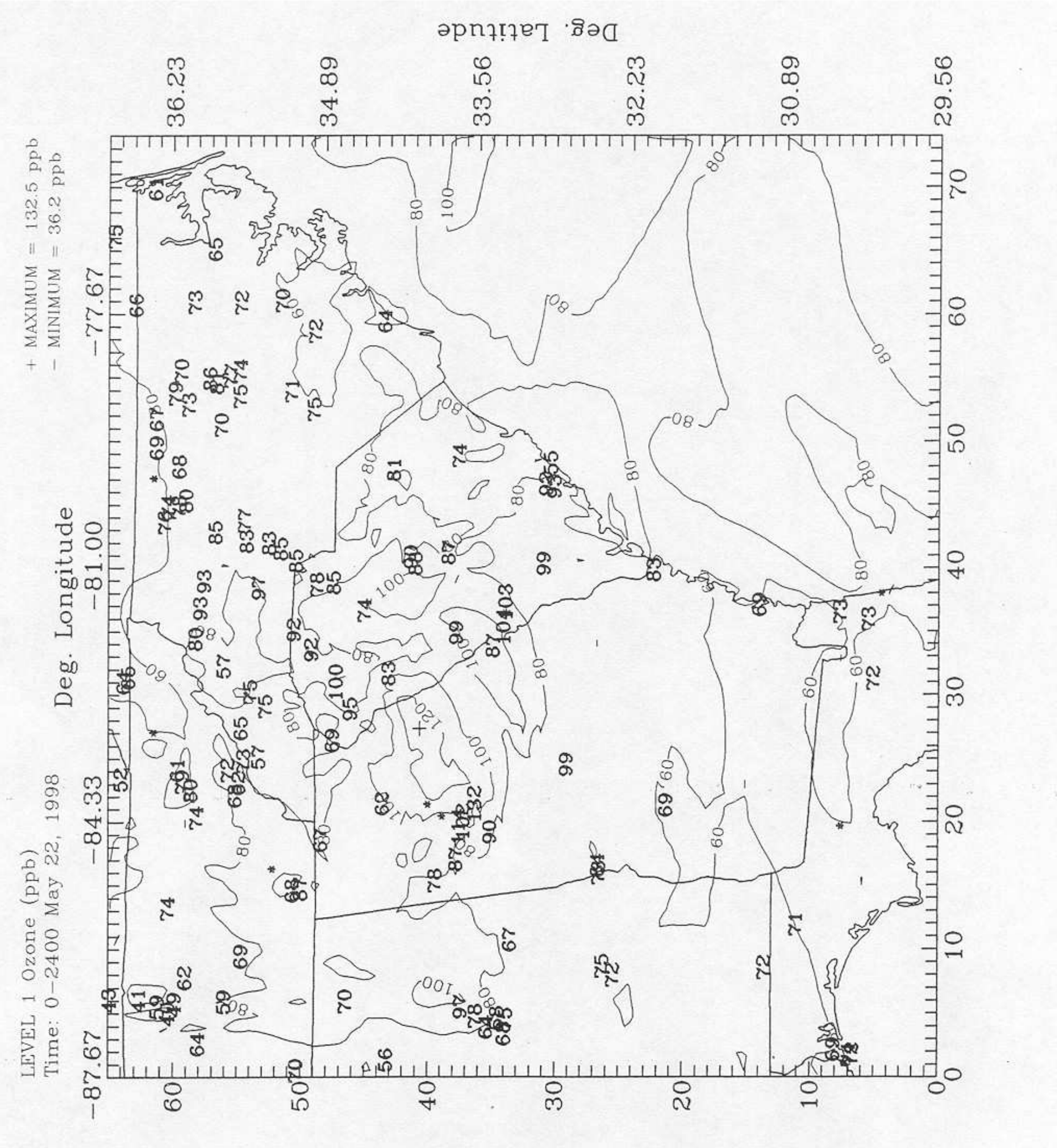

FIGURE 6-2g. Daily maximum UAM-V simulated 1-hour ozone concentration (ppb) for SCDHEC Grid 2: 22 May 1998. Observed values are shown in bold.

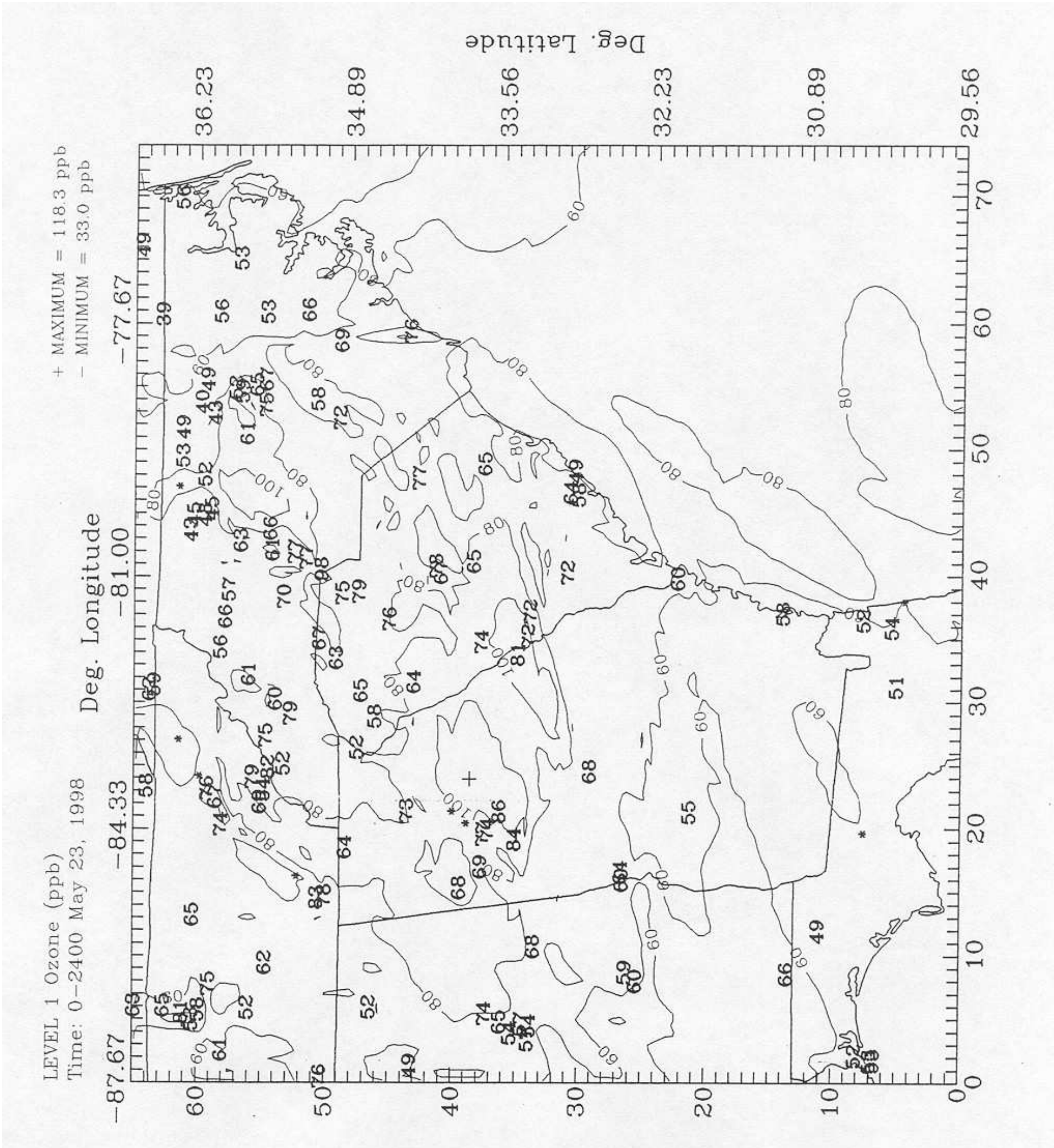

FIGURE 6-2h. Daily maximum UAM-V simulated 1-hour ozone concentration (ppb) for SCDHEC Grid 2: 23 May 1998. Observed values are shown in bold.

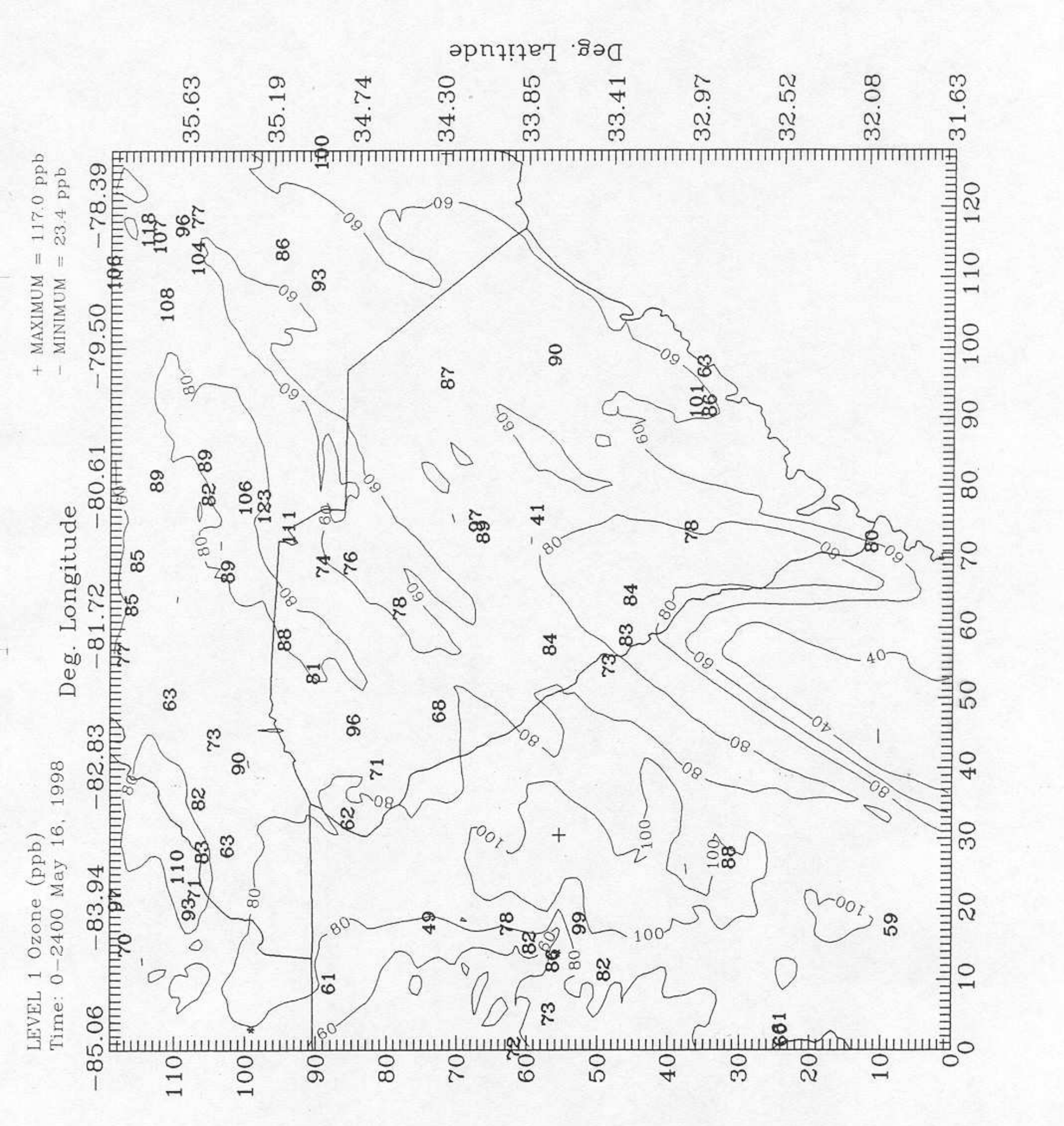

FIGURE 6-3a. Daily maximum UAM-V simulated 1-hour ozone concentration (ppb) for SCDHEC Grid 3: 16 May 1998. Observed values are shown in bold.

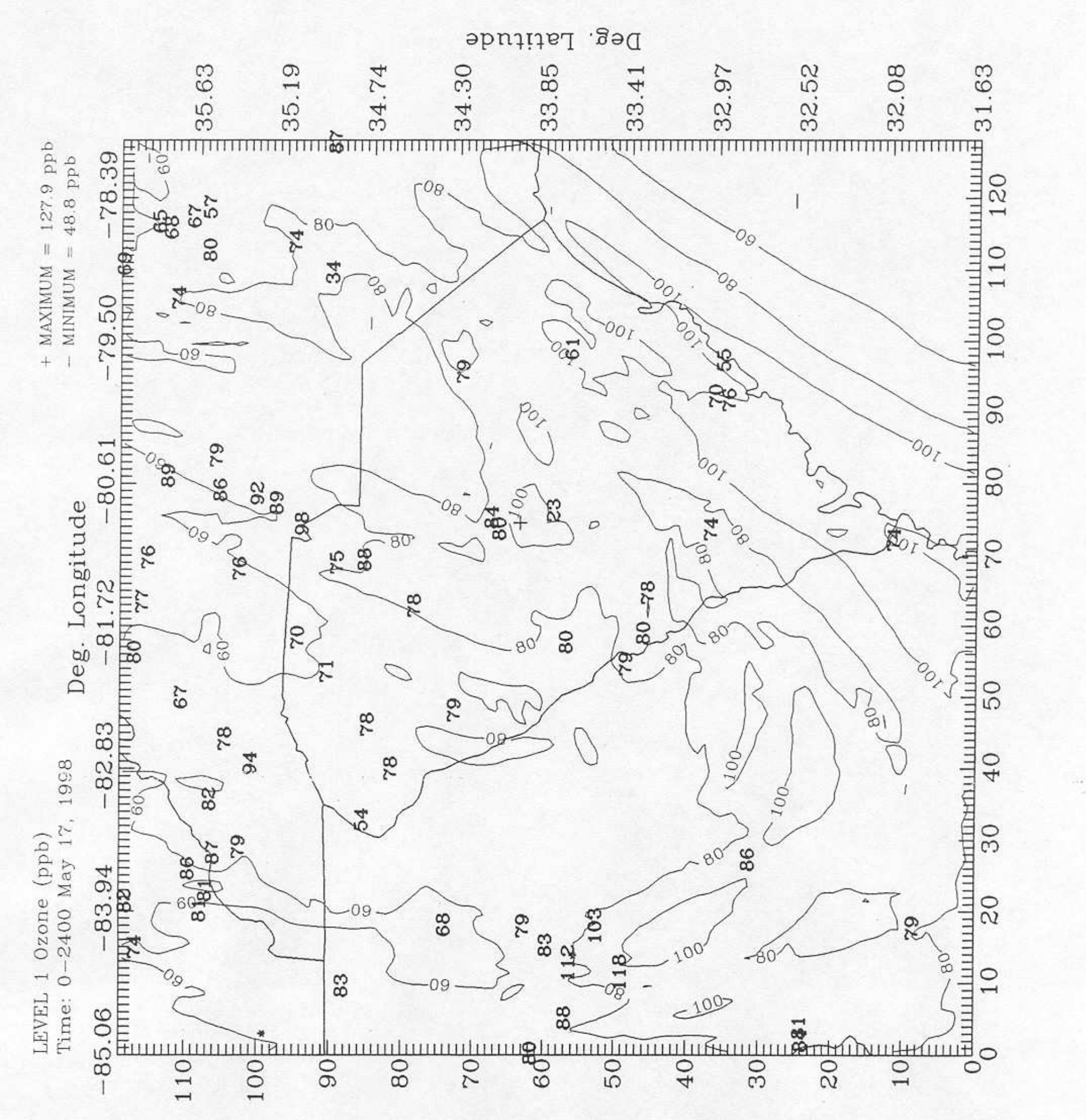

FIGURE 6-3b. Daily maximum UAM-V simulated 1-hour ozone concentration (ppb) for SCDHEC Grid 3: 17 May 1998. Observed values are shown in bold.

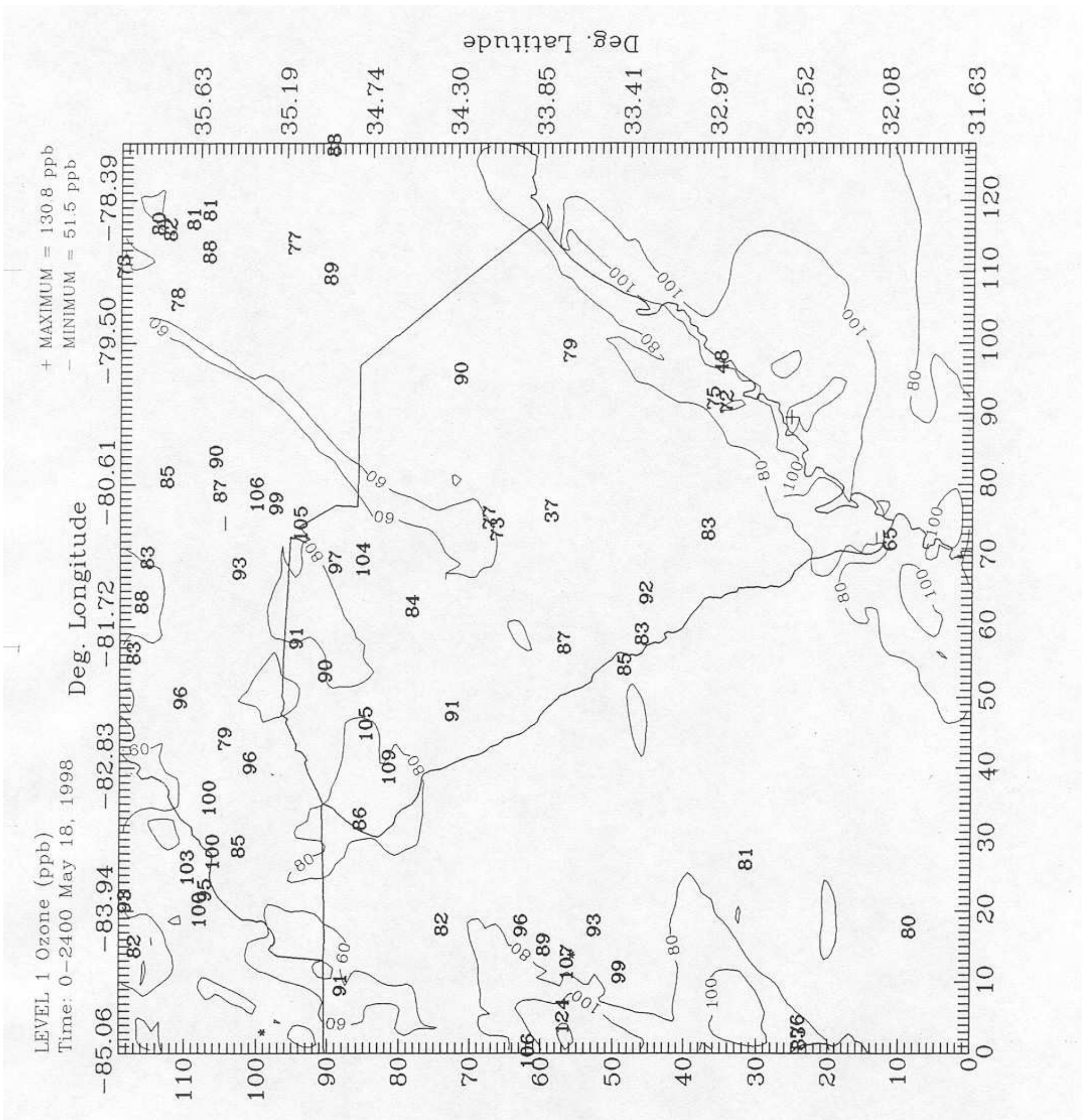

FIGURE 6-3c. Daily maximum UAM-V simulated 1-hour ozone concentration (ppb) for SCDHEC Grid 3: 18 May 1998. Observed values are shown in bold.

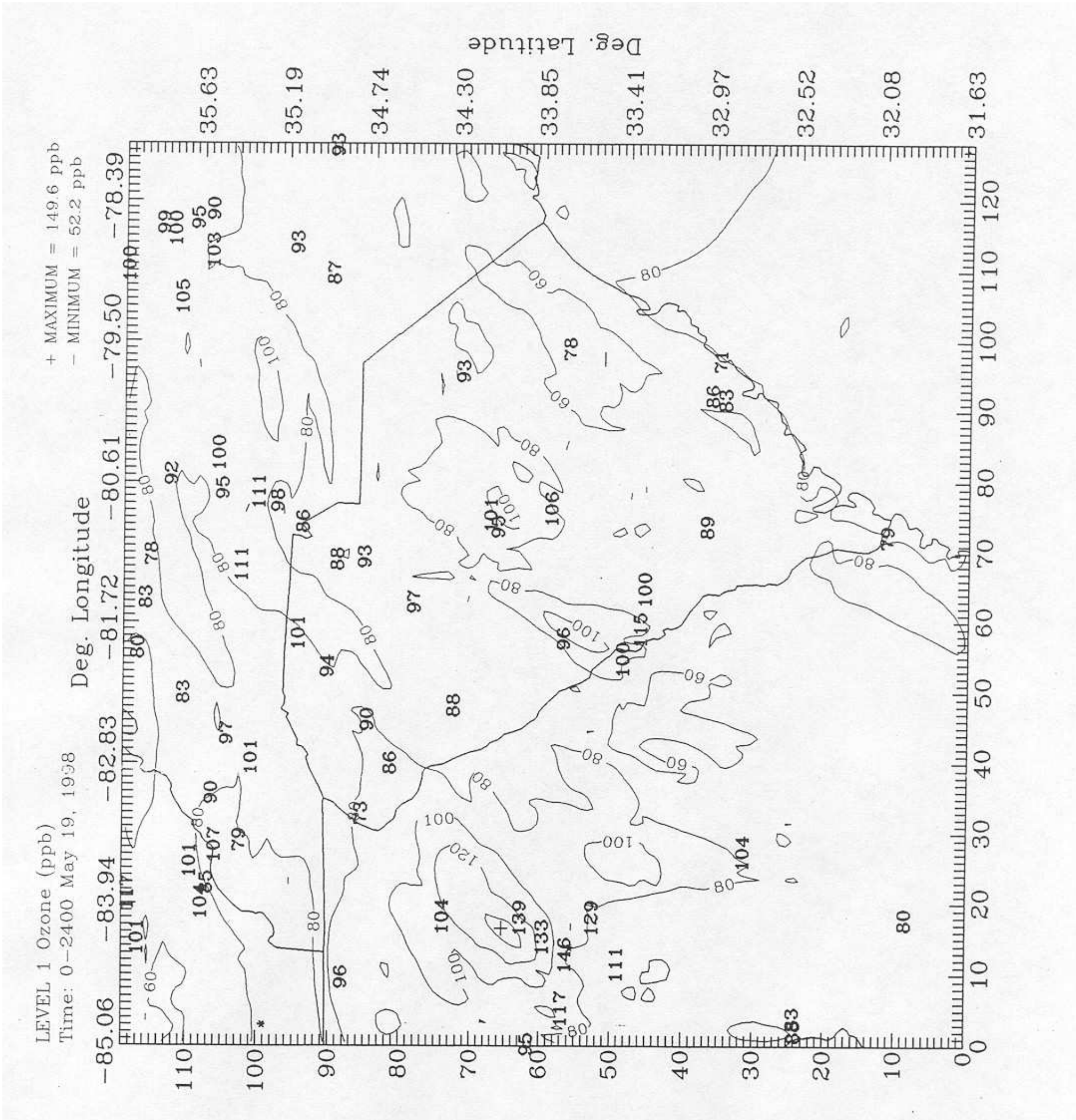

FIGURE 6-3d. Daily maximum UAM-V simulated 1-hour ozone concentration (ppb) for SCDHEC Grid 3: 19 May 1998. Observed values are shown in bold.

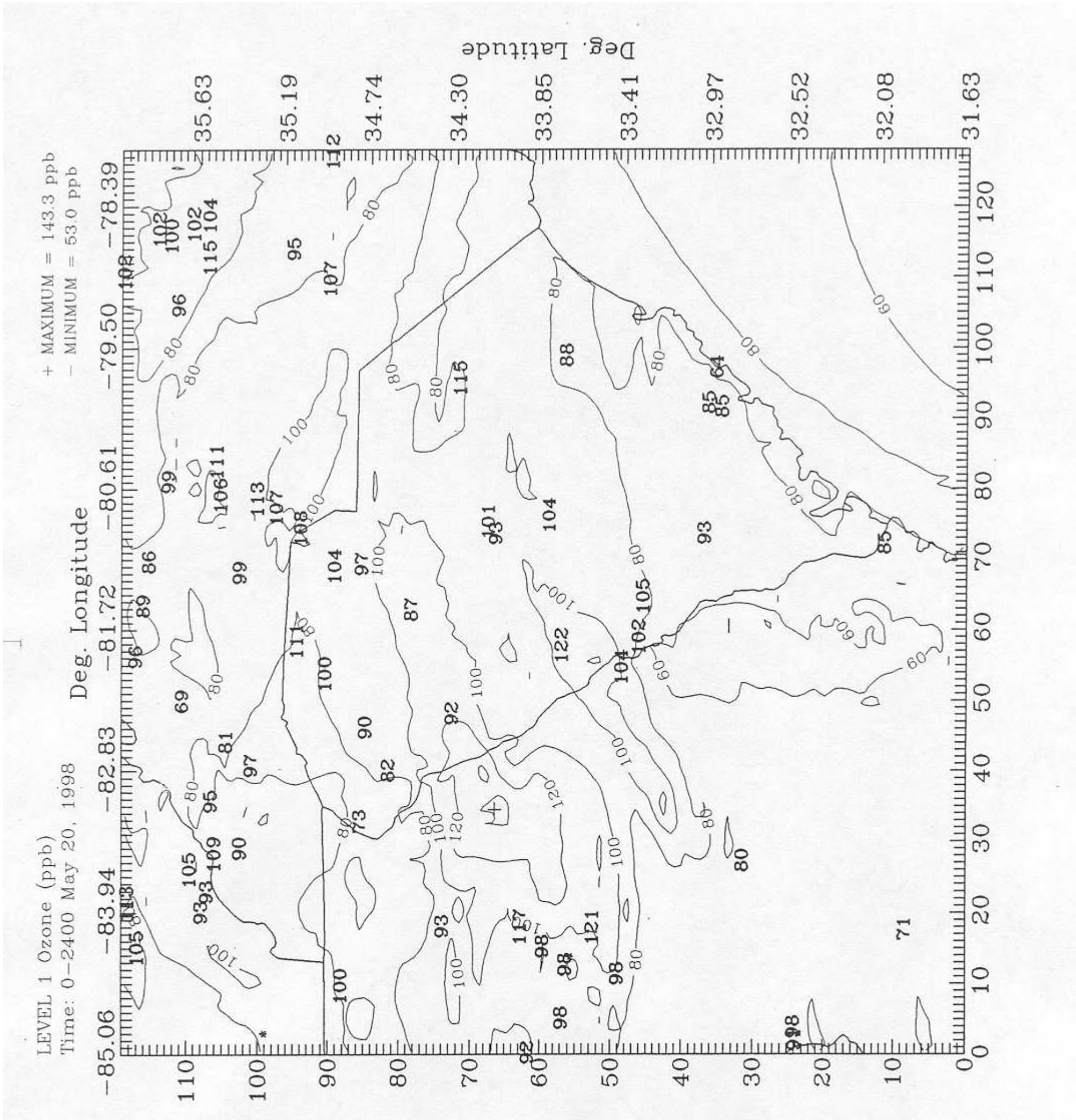

FIGURE 6-3e. Daily maximum UAM-V simulated 1-hour ozone concentration (ppb) for SCDHEC Grid 3: 20 May 1998. Observed values are shown in bold.

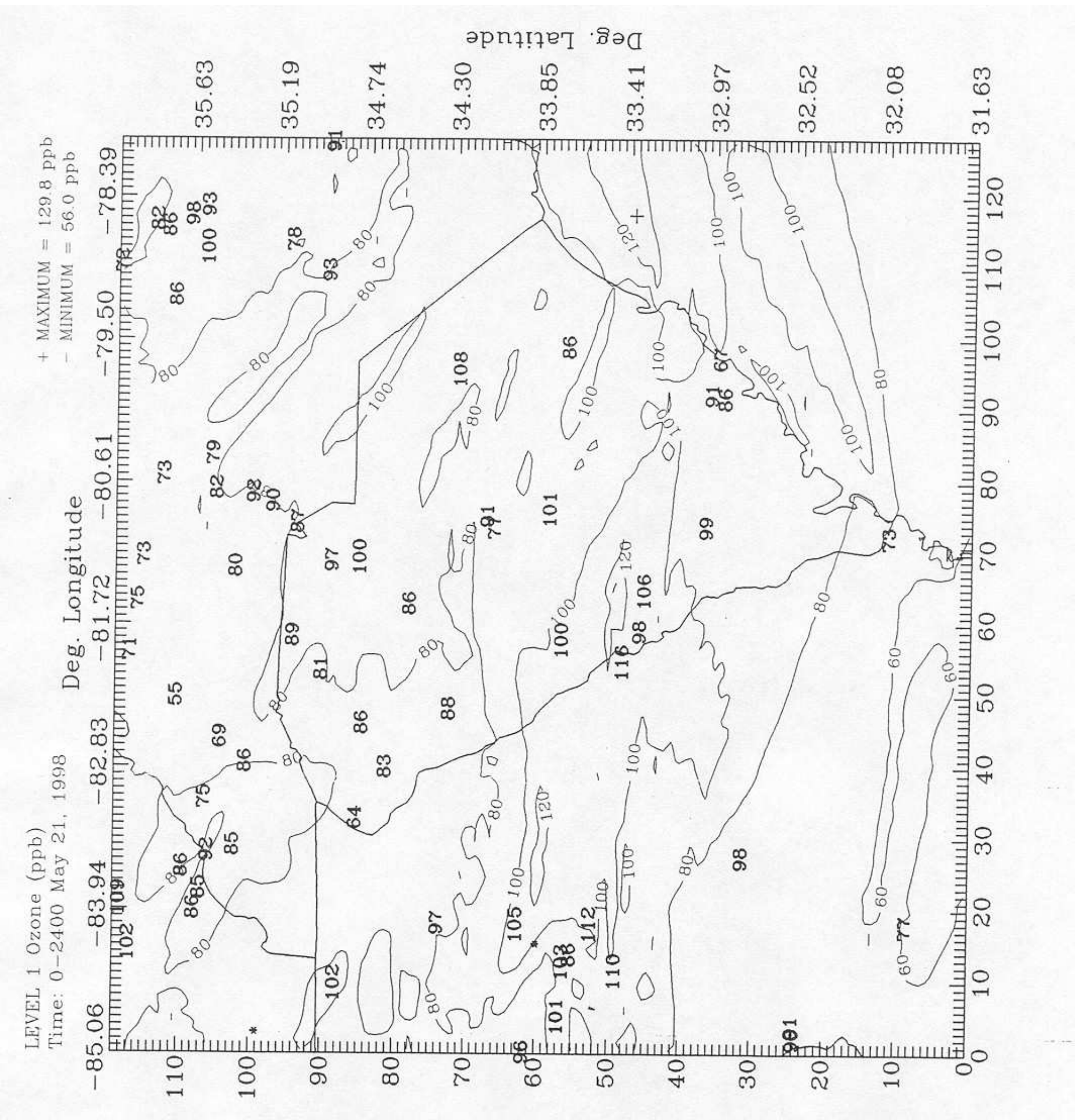

FIGURE 6-3f. Daily maximum UAM-V simulated 1-hour ozone concentration (ppb) for SCDHEC Grid 3: 21 May 1998. Observed values are shown in bold.

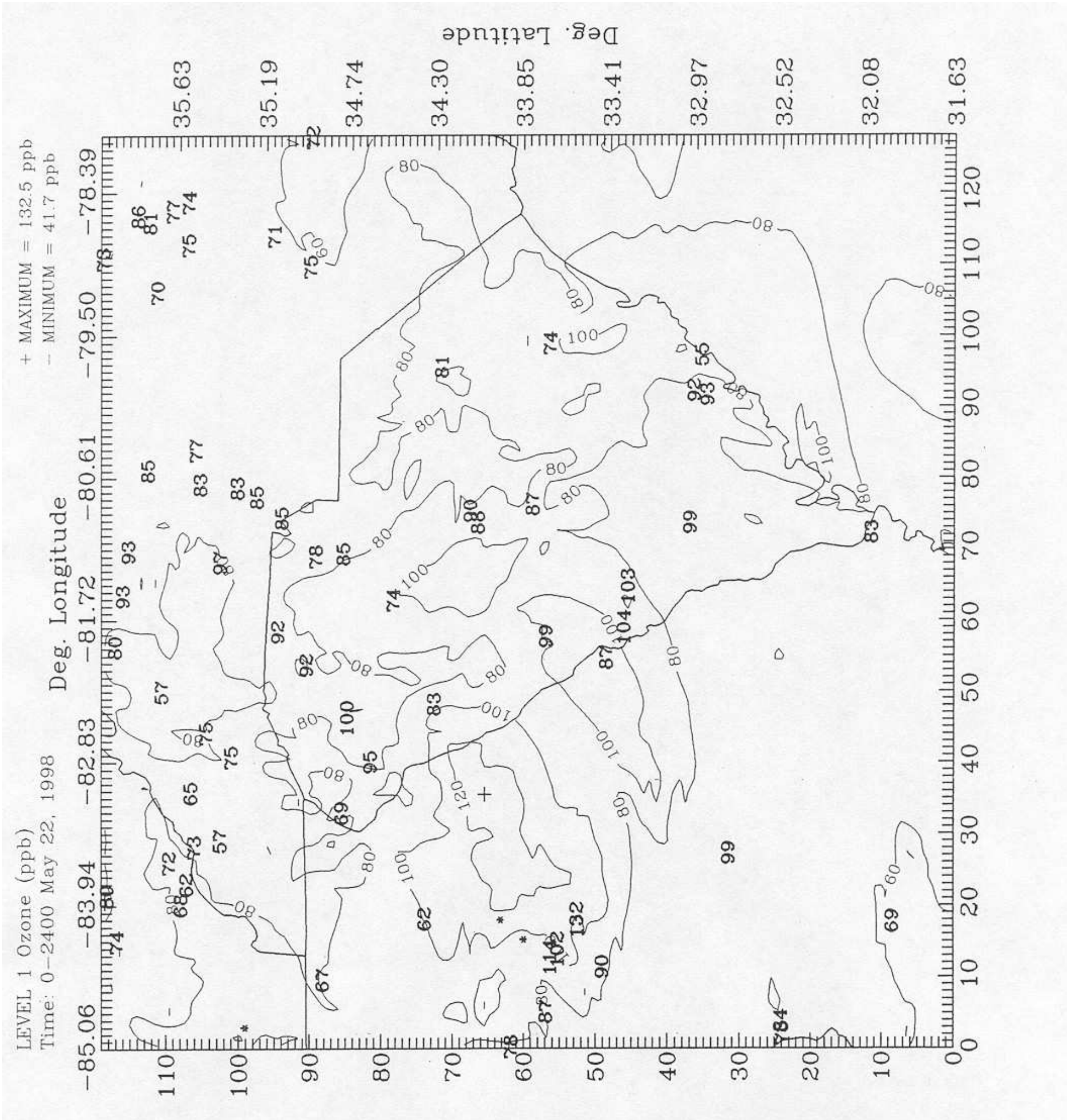

FIGURE 6-3g. Daily maximum UAM-V simulated 1-hour ozone concentration (ppb) for SCDHEC Grid 3: 22 May 1998. Observed values are shown in bold.

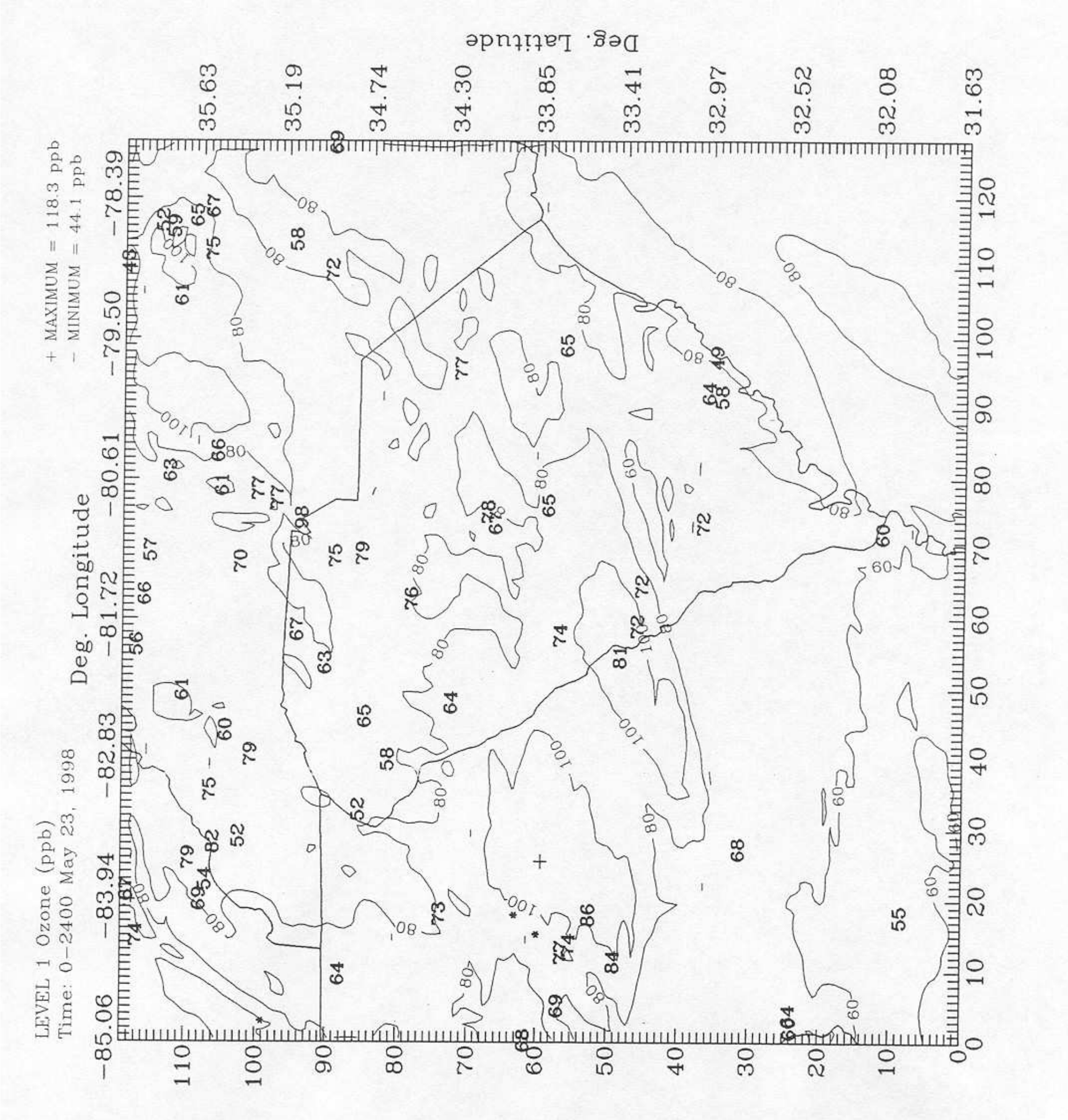

FIGURE 6-3h. Daily maximum UAM-V simulated 1-hour ozone concentration (ppb) for SCDHEC Grid 3: 23 May 1998. Observed values are shown in bold.

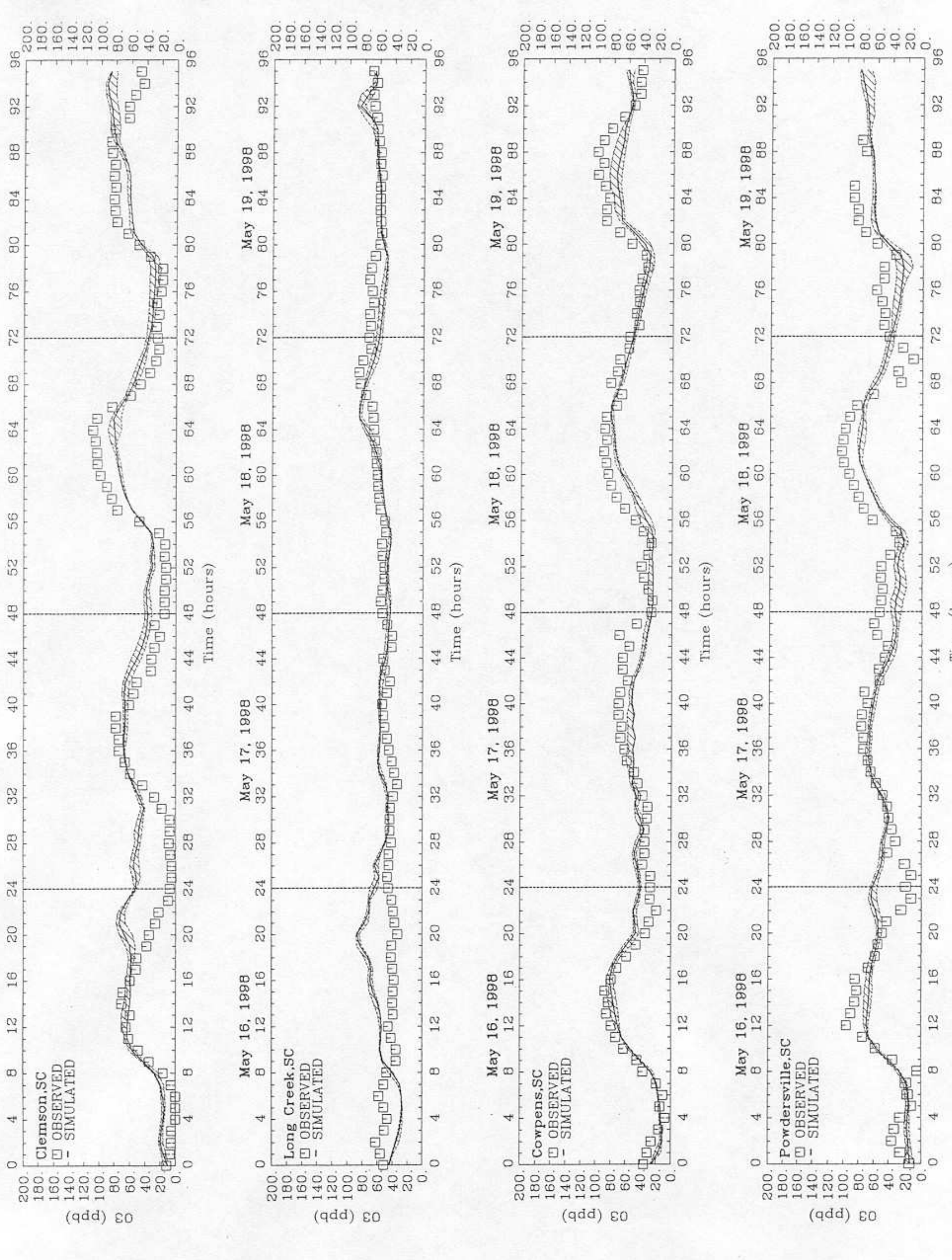

FIGURE 6–4a. Time–series plots comparing simulated and observed ozone concentrations for 16 – 19 May 1998: Anderson/Greenville/Spartanburg(SC) monitor

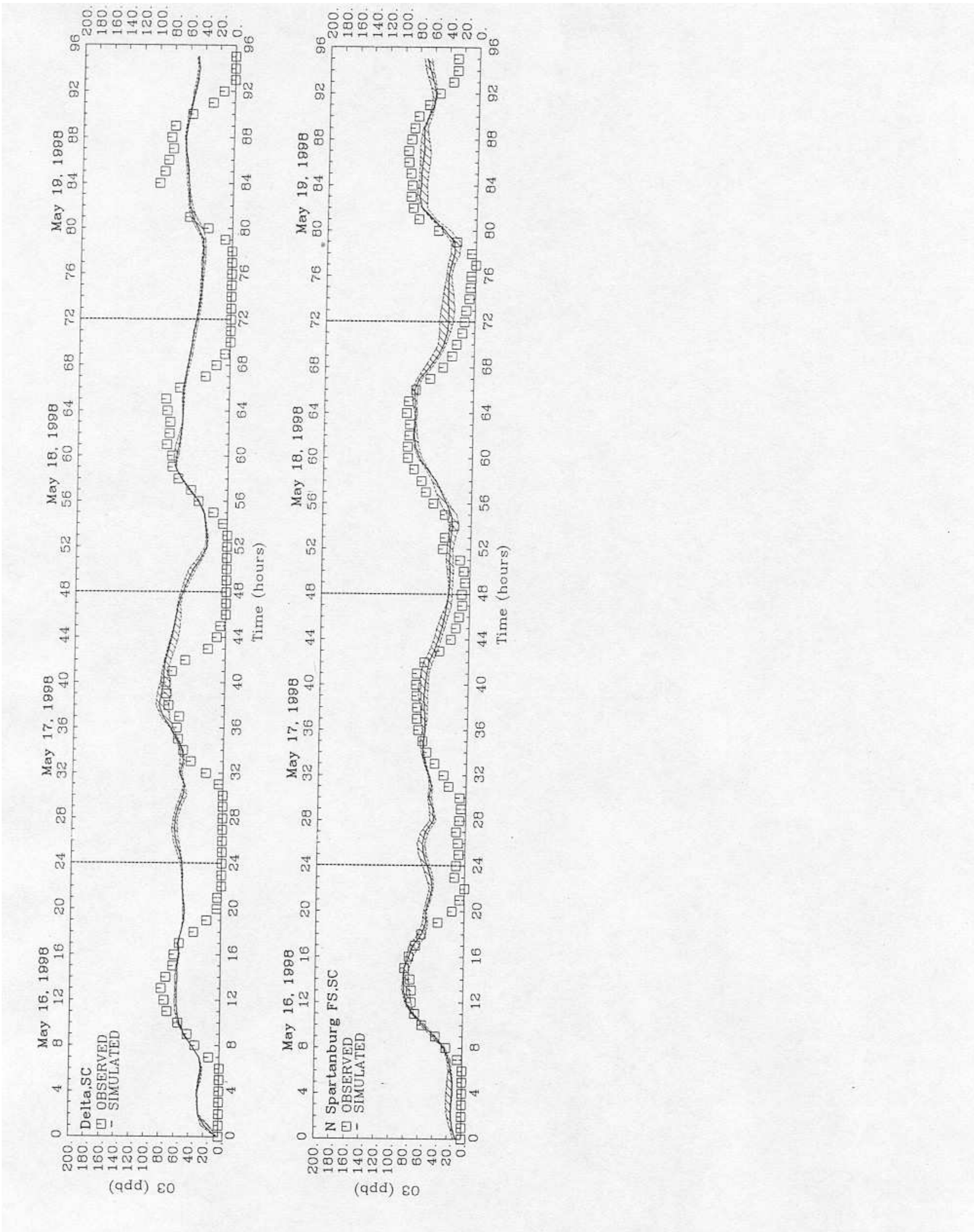

FIGURE 6–4a. Continued.

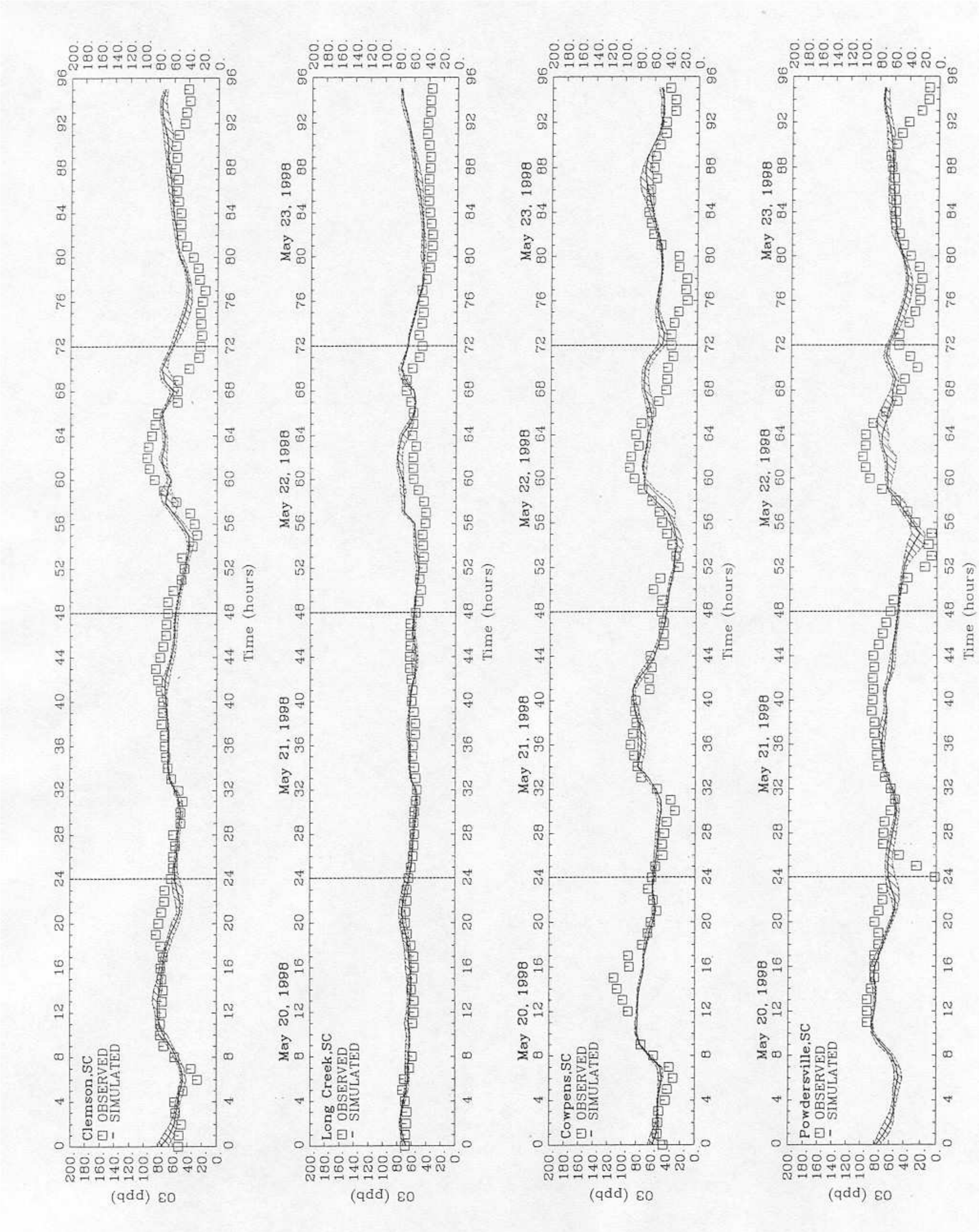

FIGURE 6-4a. Time-series plots comparing simulated and observed ozone concentrations for 20 - 23 May 1998: Anderson/Greenville/Spartanburg(SC) monitor

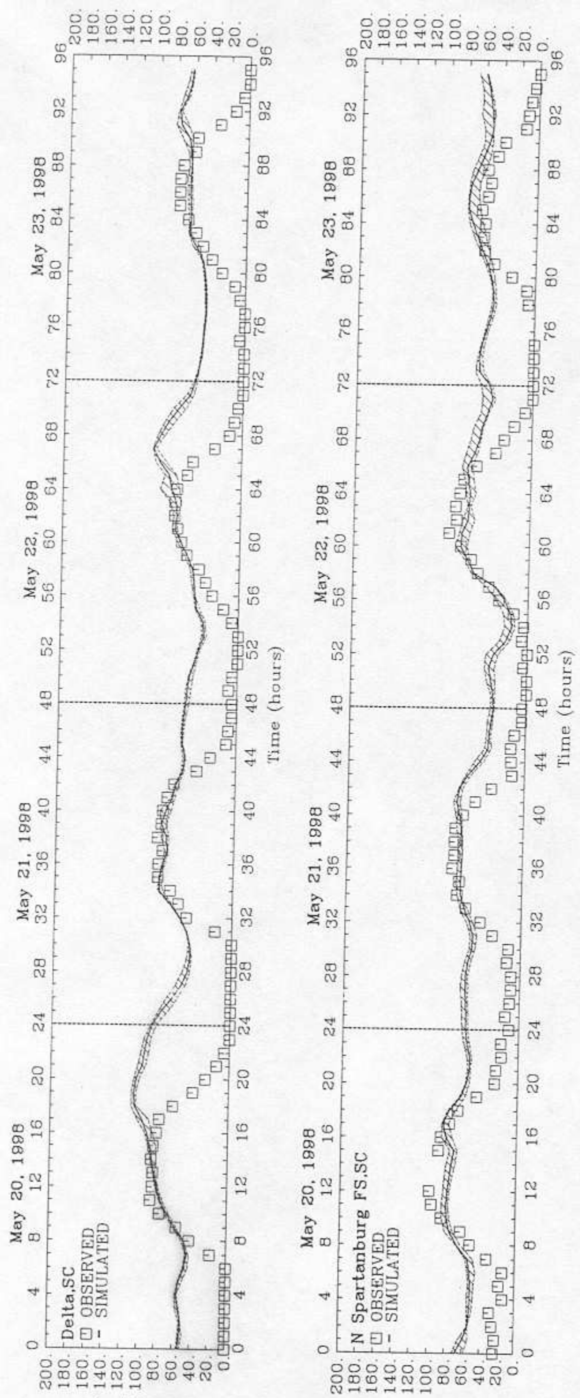

FIGURE 6-4a. Concluded.

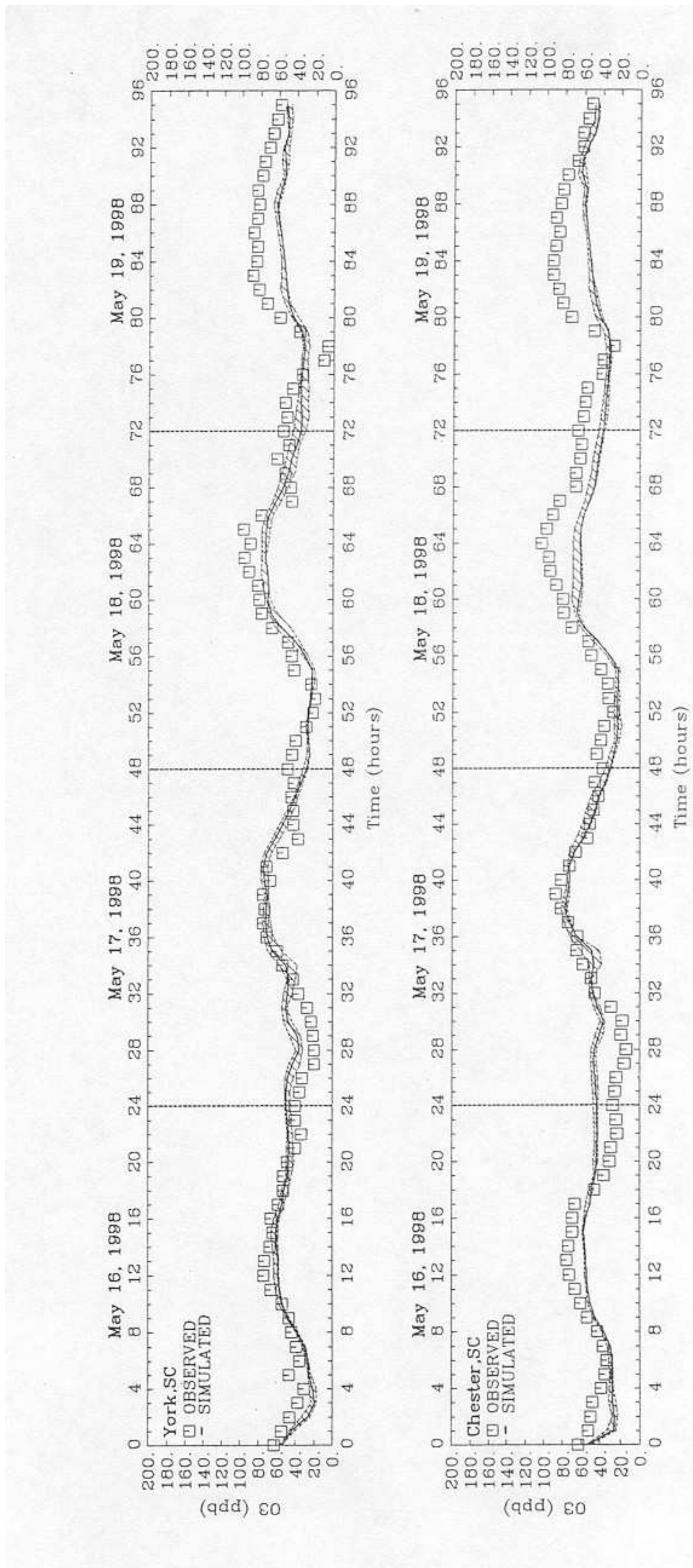

FIGURE 6-4b. Time-series plots comparing simulated and observed ozone concentrations for 16 – 19 May 1998: Rock Hill(SC) monitoring sites.

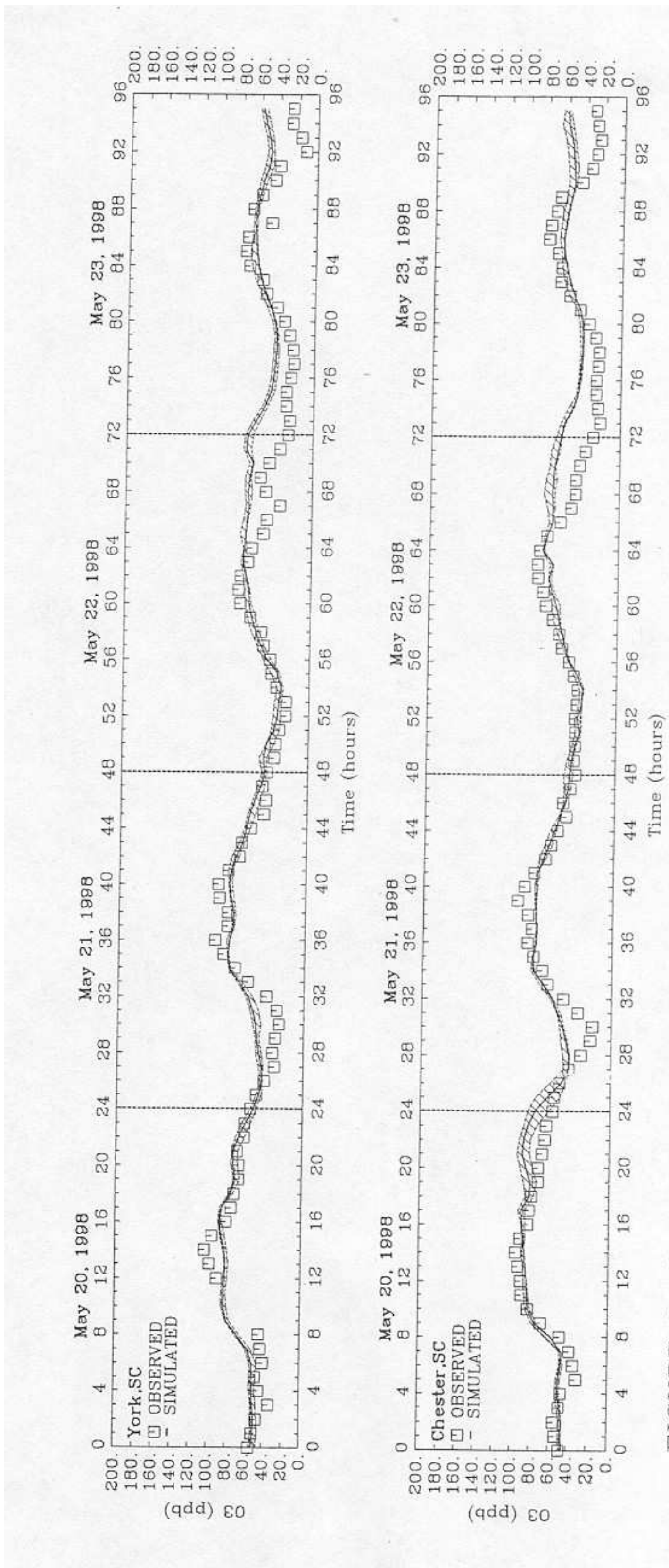

FIGURE 6-4b. Time-series plots comparing simulated and observed ozone concentrations for 20 – 23 May 1998: Rock Hill(SC) monitoring sites.

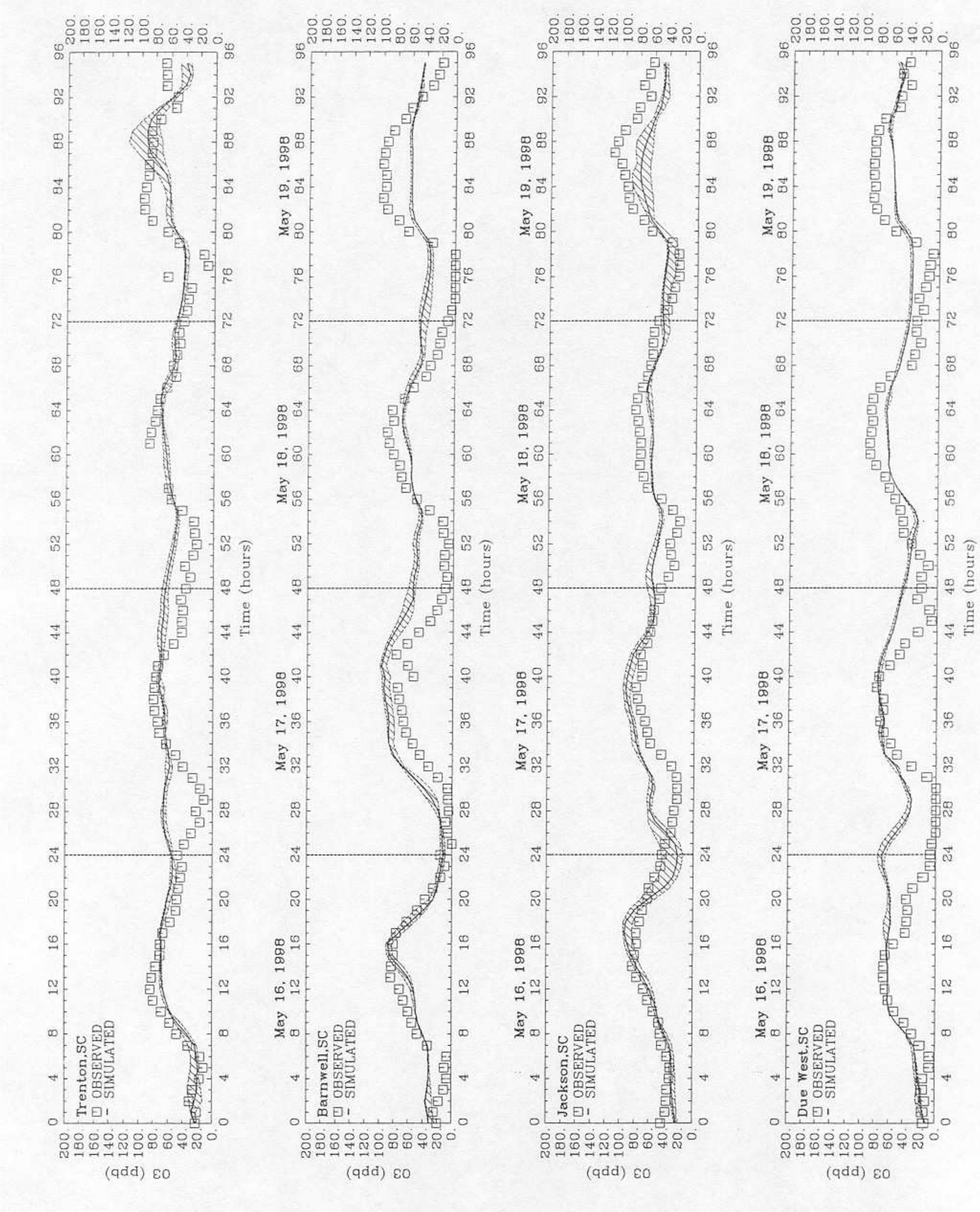

FIGURE 6-4c. Time-series plots comparing simulated and observed ozone concentrations for 16 – 19 May 1998: Columbia/Aiken(SC) monitoring sites.

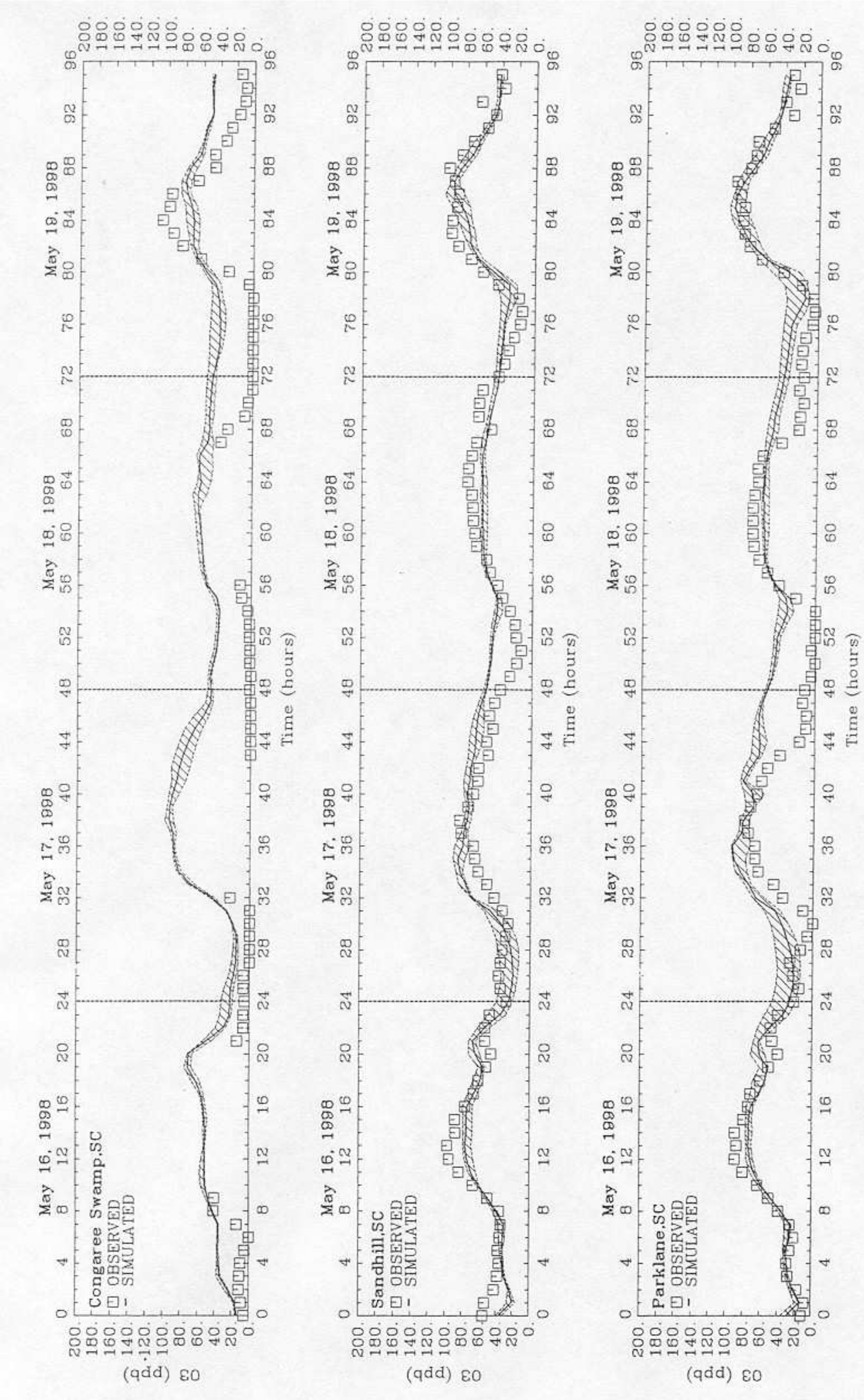

FIGURE 6-4c. Continued.

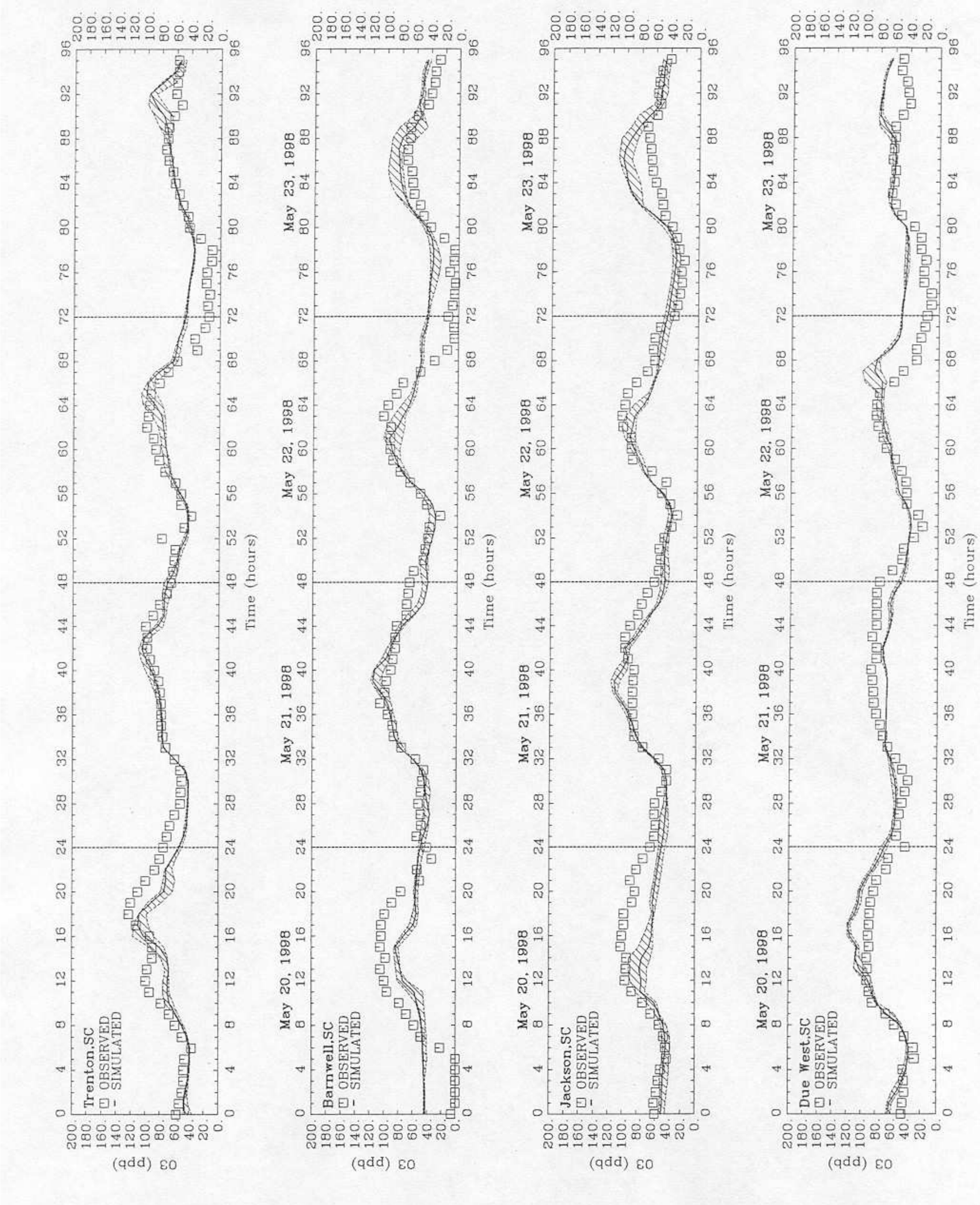

FIGURE 6-4c. Time-series plots comparing simulated and observed ozone concentrations for 20 – 23 May 1998: Columbia/Aiken(SC) monitoring sites.

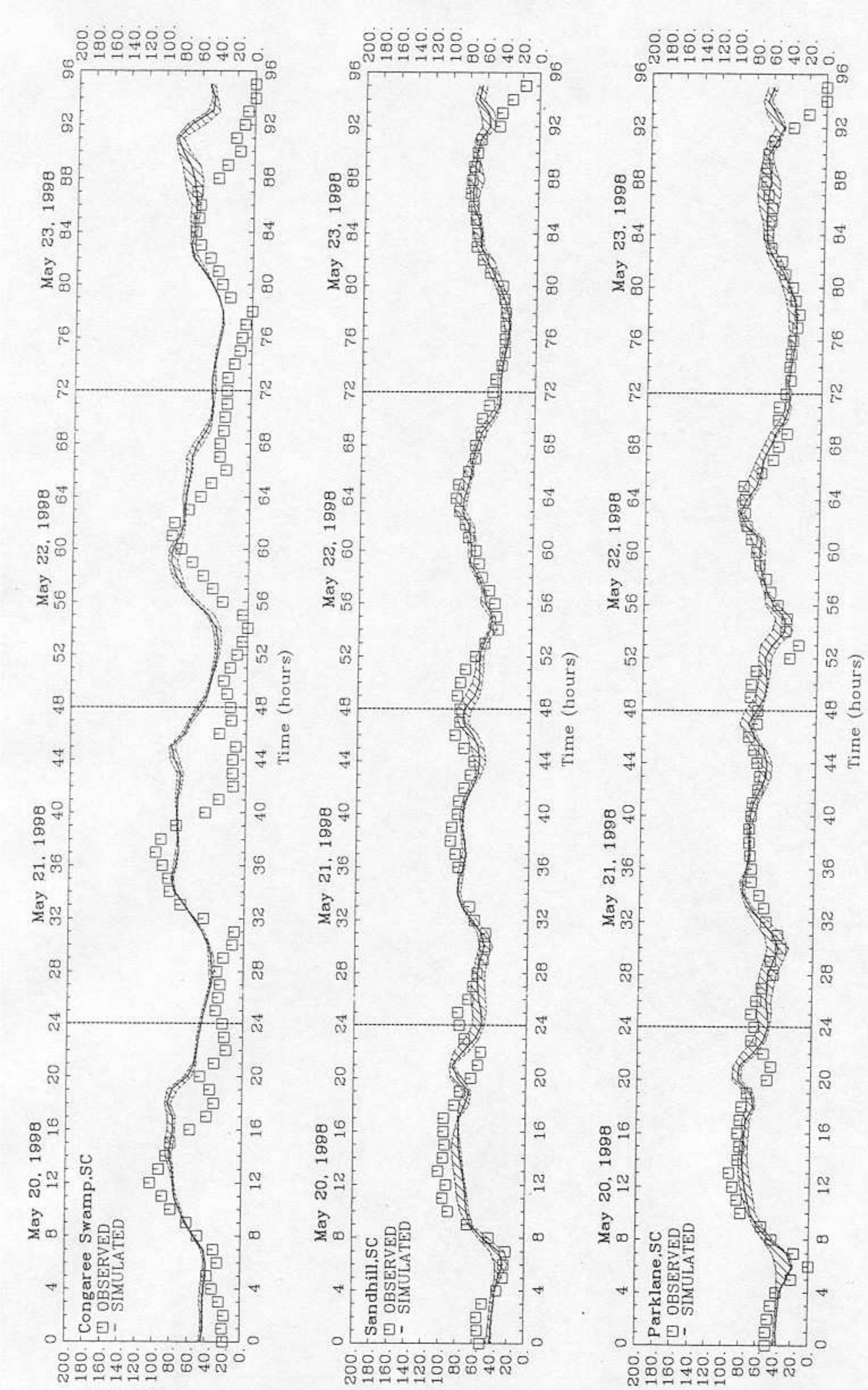

FIGURE 6-4c. Concluded.

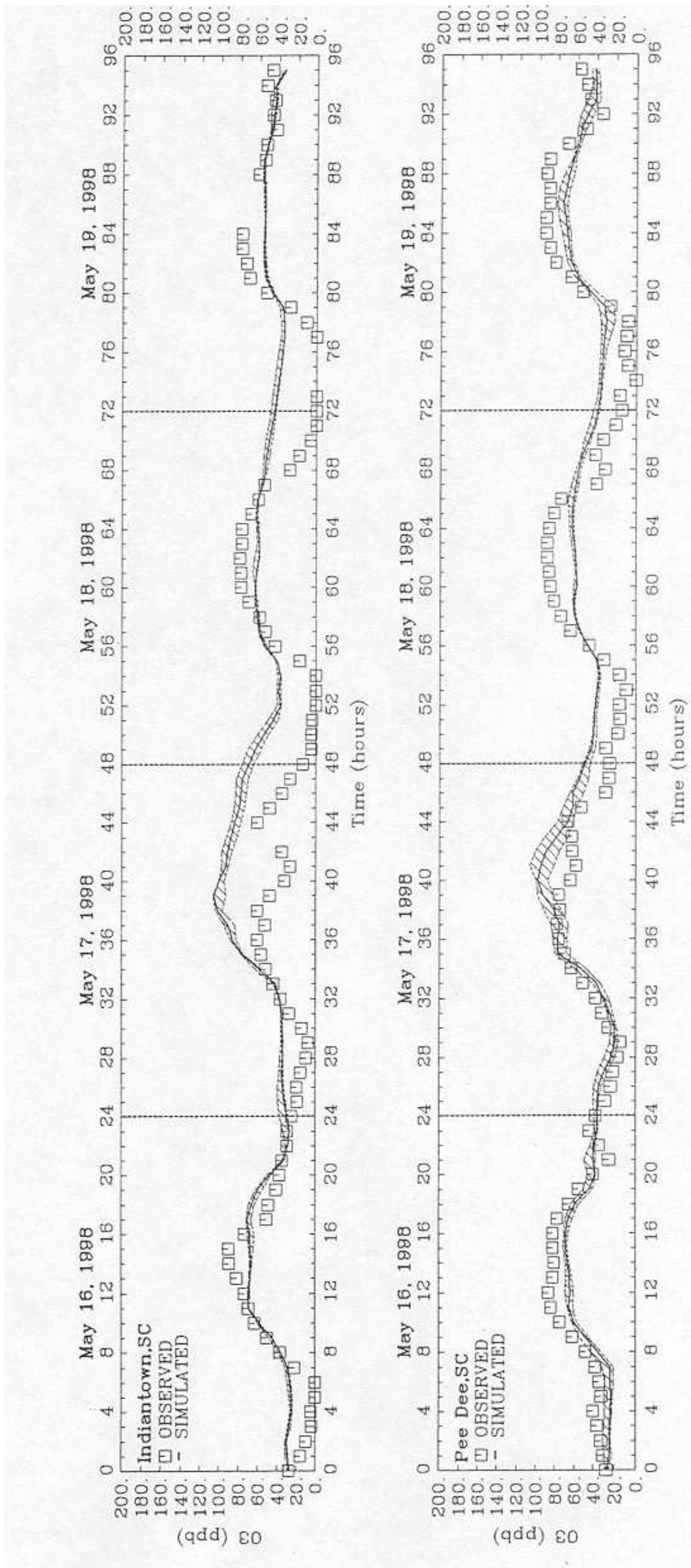

FIGURE 6–4d. Time–series plots comparing simulated and observed ozone concentrations for 16 – 19 May 1998: Florence/Darlington(SC) monitoring sites.

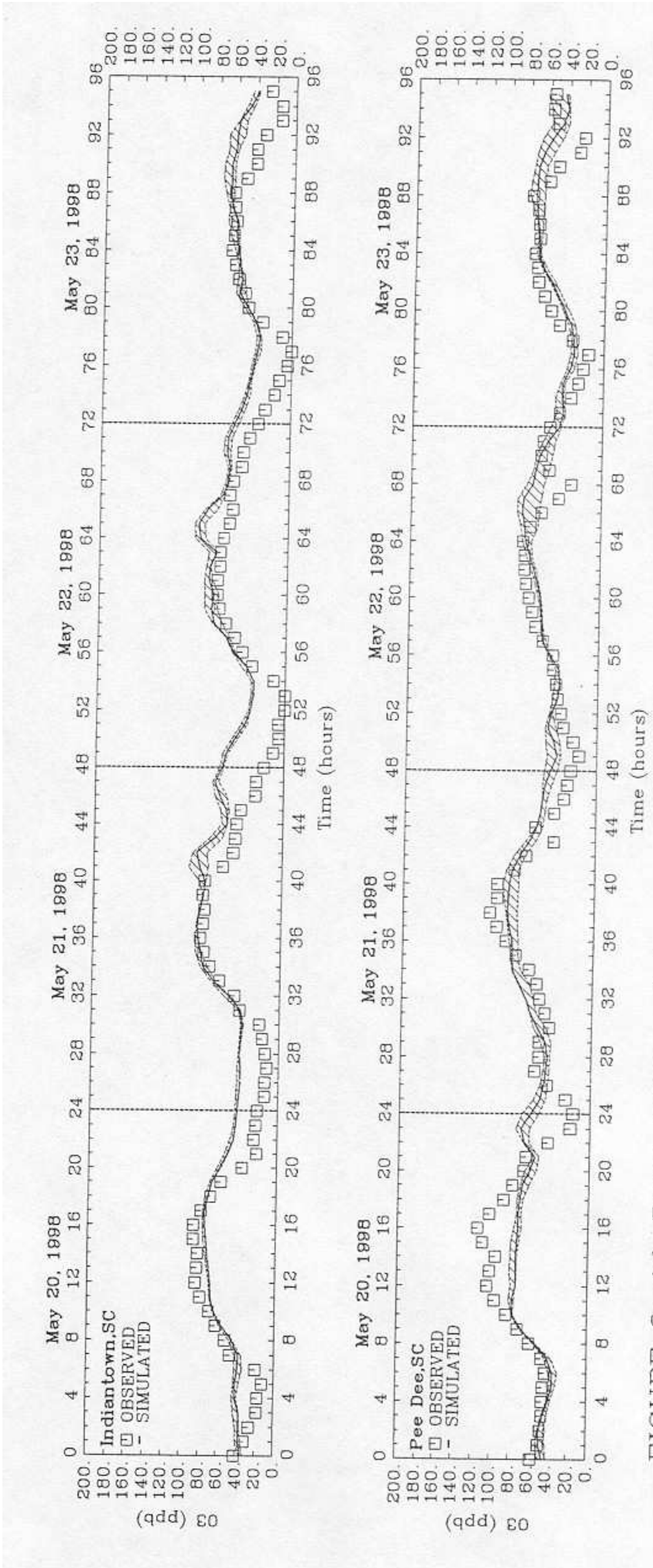

FIGURE 6-4d. Time-series plots comparing simulated and observed ozone concentrations for 20 - 23 May 1998: Florence/Darlington(SC) monitoring sites.

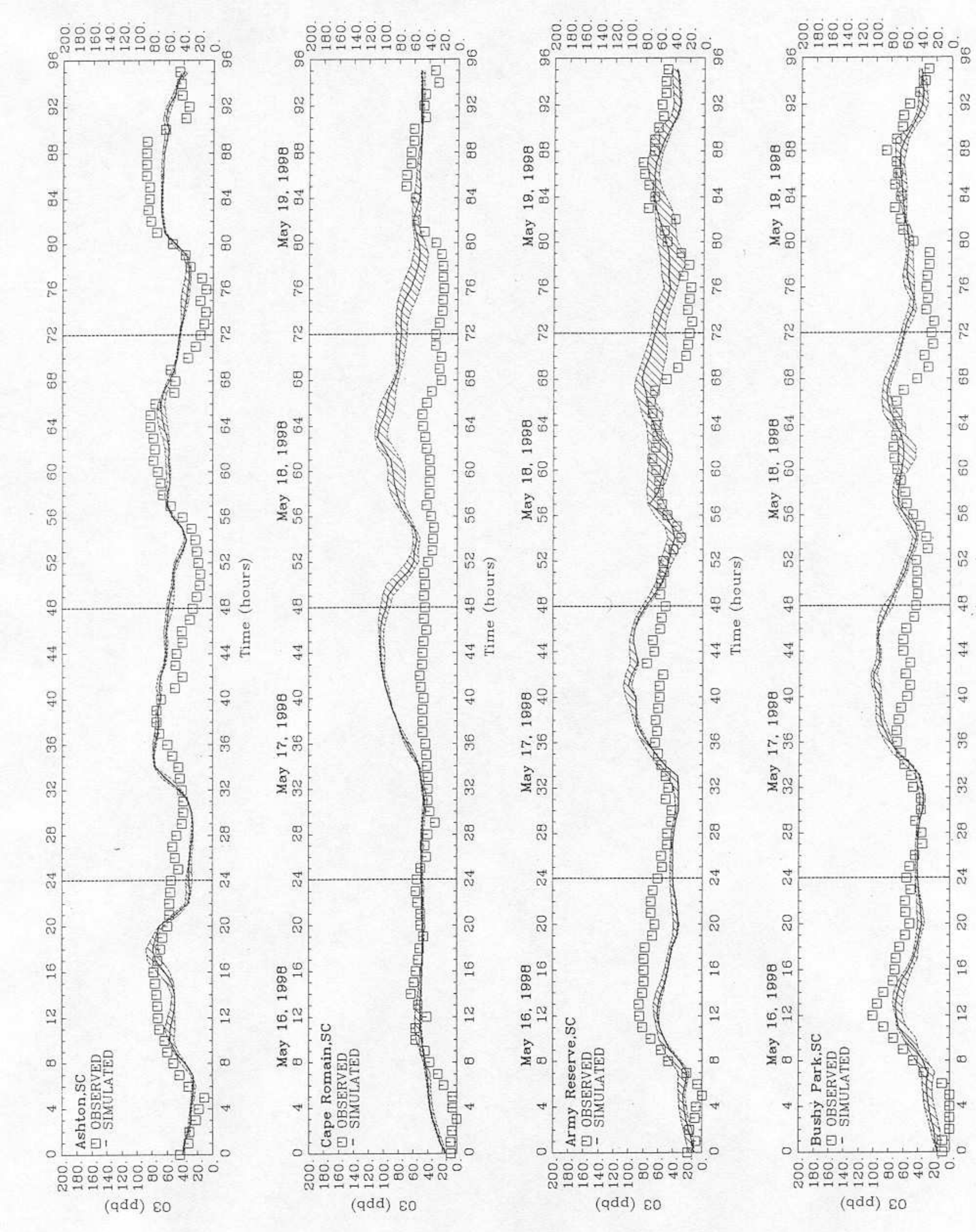

FIGURE 6-4e. Time-series plots comparing simulated and observed ozone concentrations for 16 – 19 May 1998: Other(SC) monitoring sites.

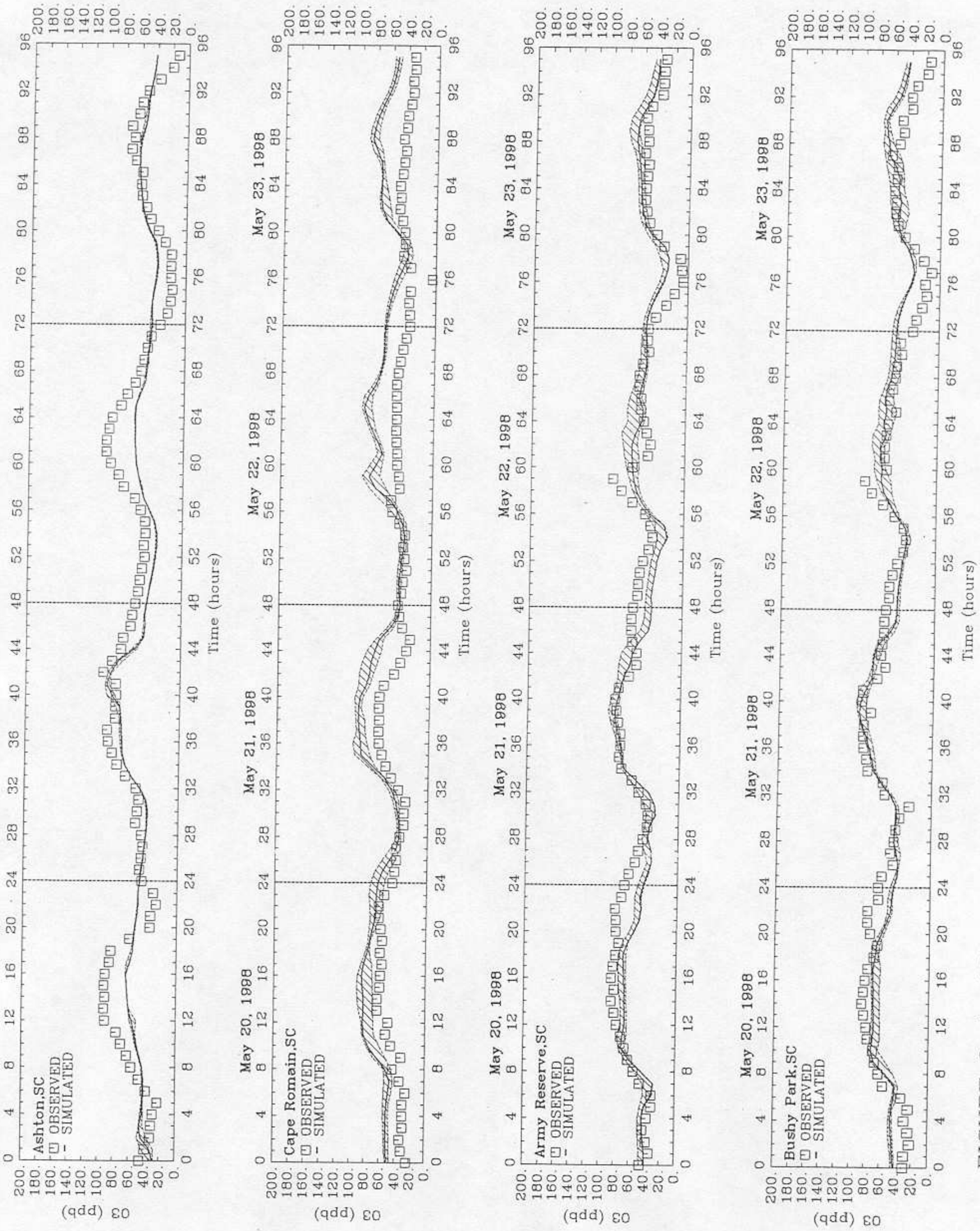

FIGURE 6-4e. Time-series plots comparing simulated and observed ozone concentrations for 20 – 23 May 1998: Other(SC) monitoring sites.

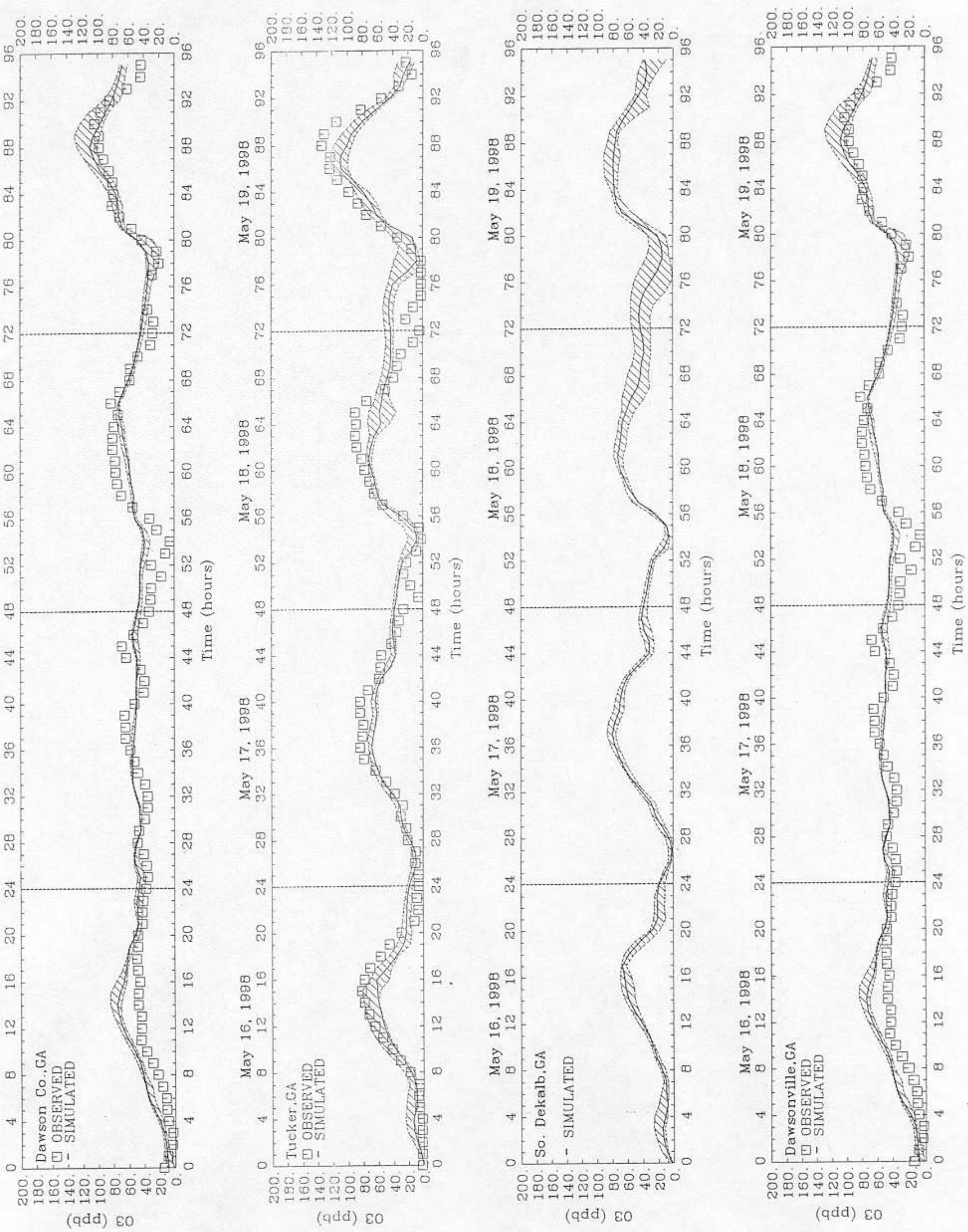

FIGURE 6-5a. Time-series plots comparing simulated and observed ozone concentrations for 16 – 19 May 1998: Atlanta (GA) monitoring sites.

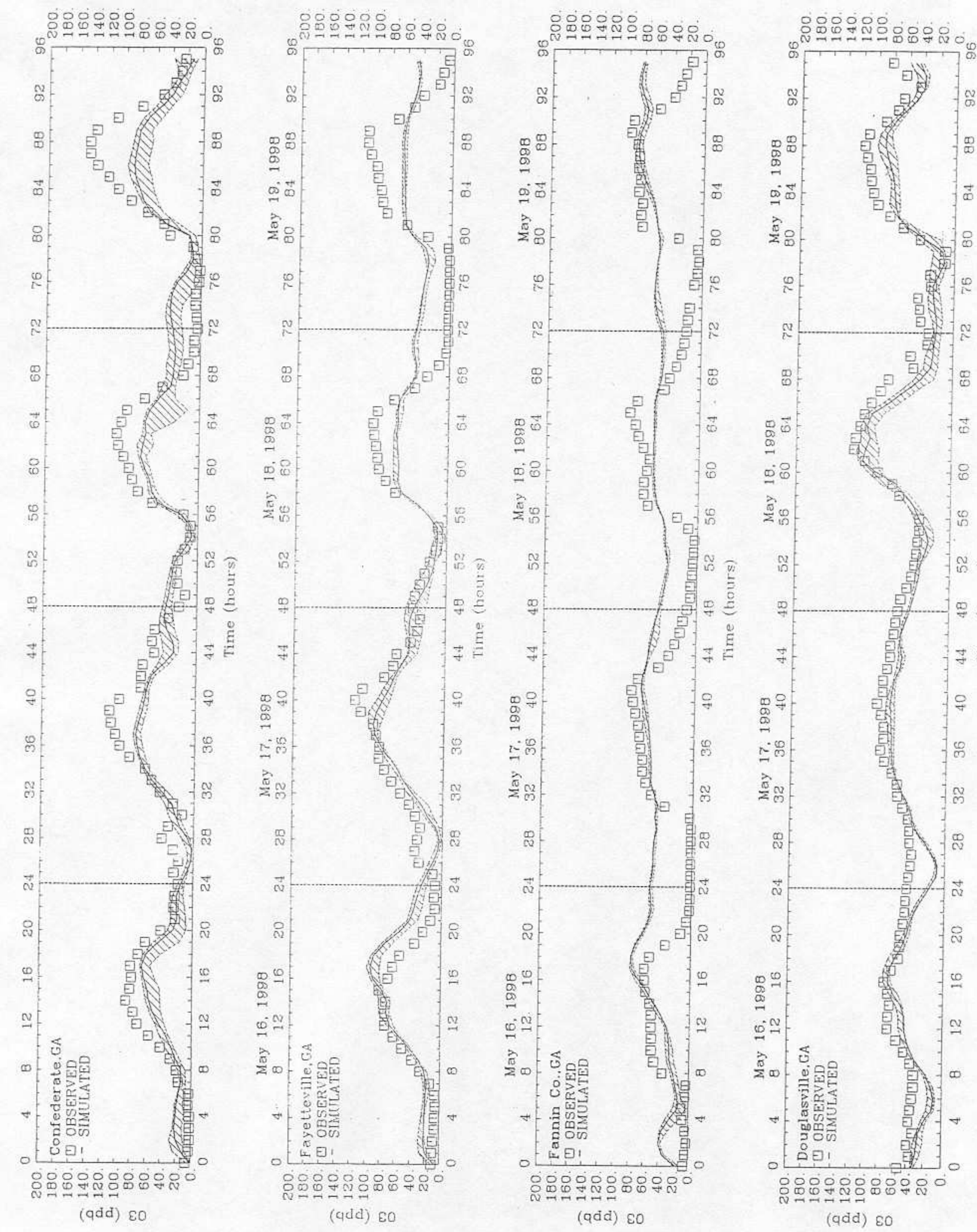

FIGURE 6-5a. Continued.

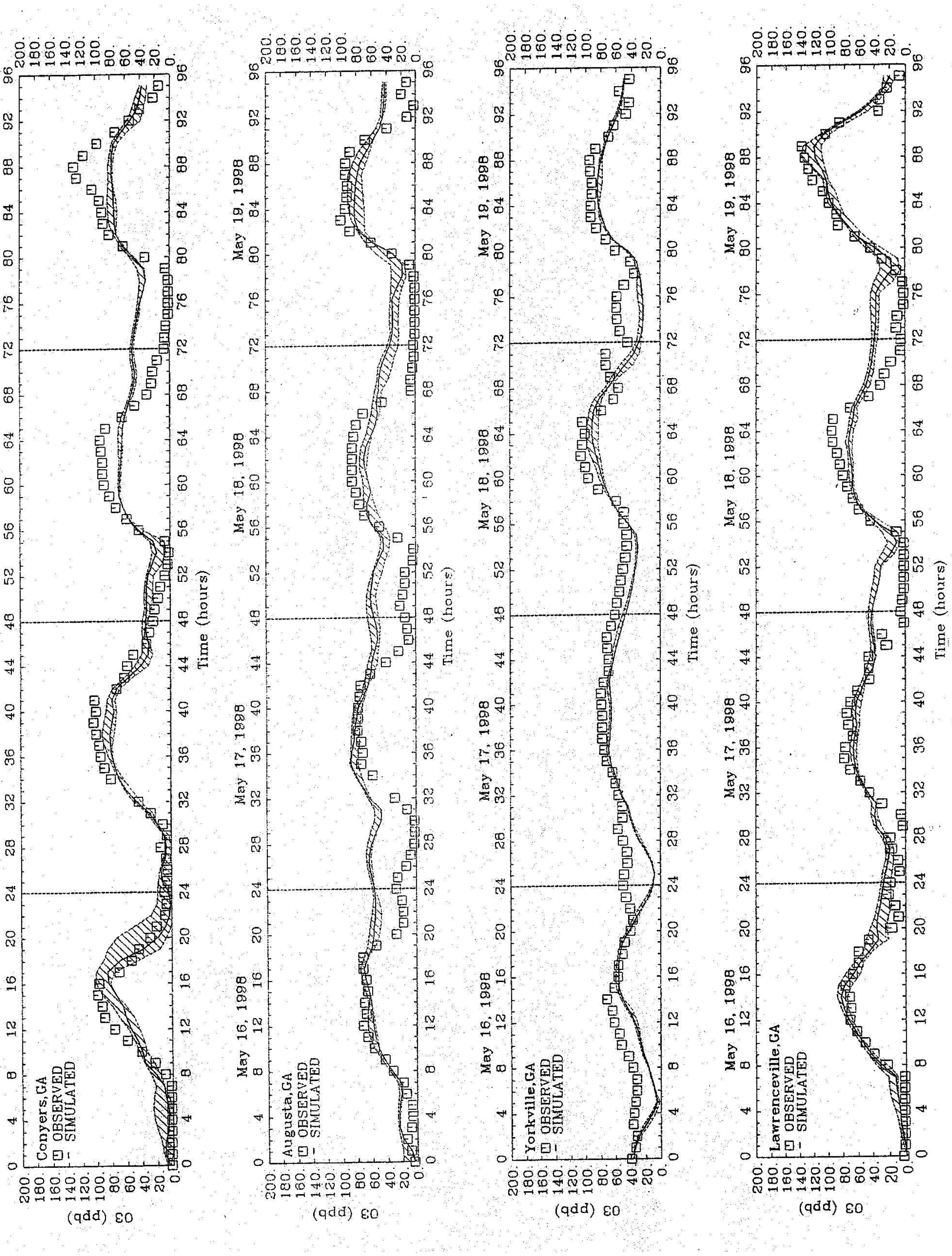

FIGURE 6-5a. Continued.

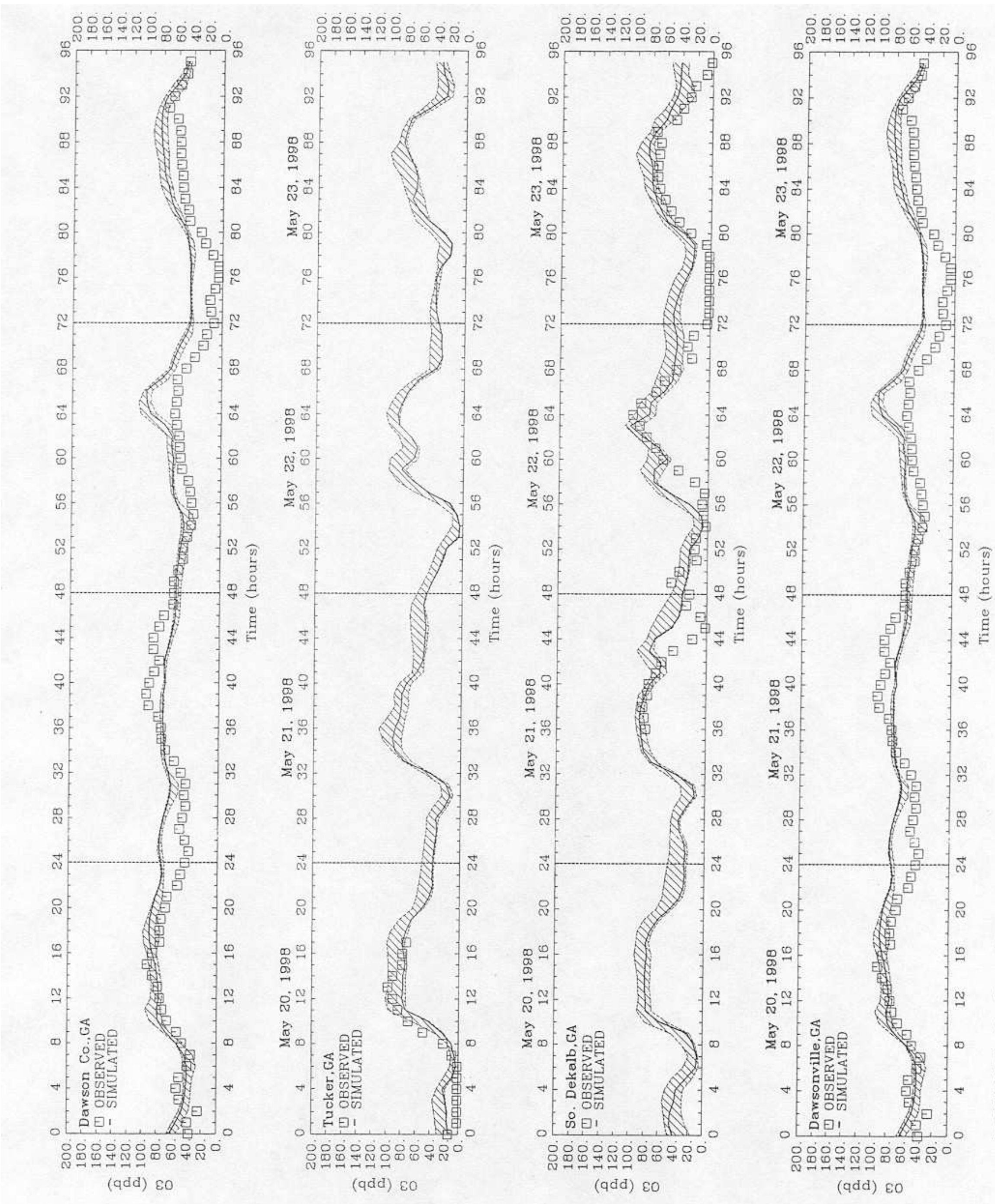

FIGURE 6-5a. Time-series plots comparing simulated and observed ozone concentrations for 20 - 23 May 1998: Atlanta (GA) monitoring sites.

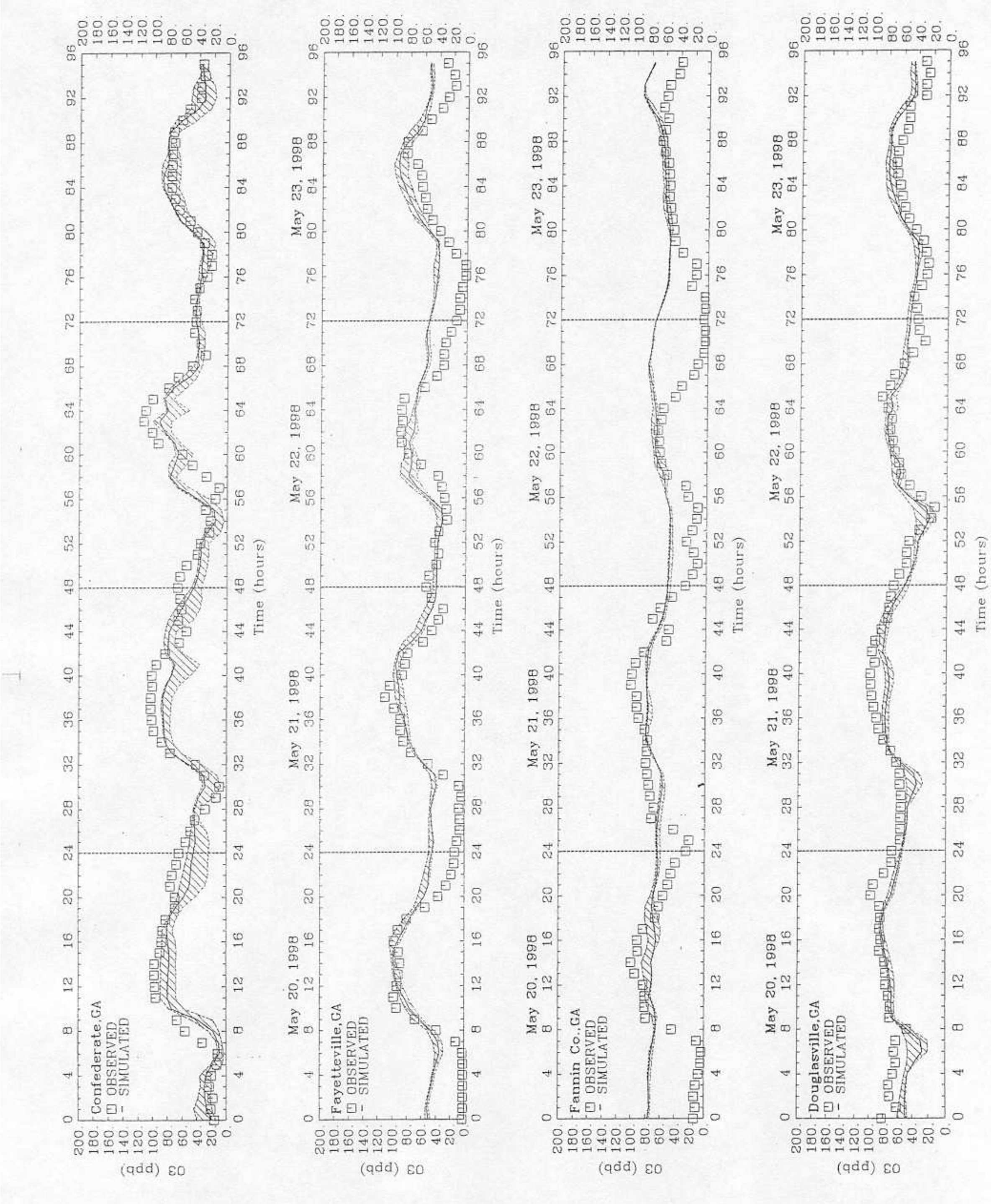

FIGURE 6-5a. Continued.

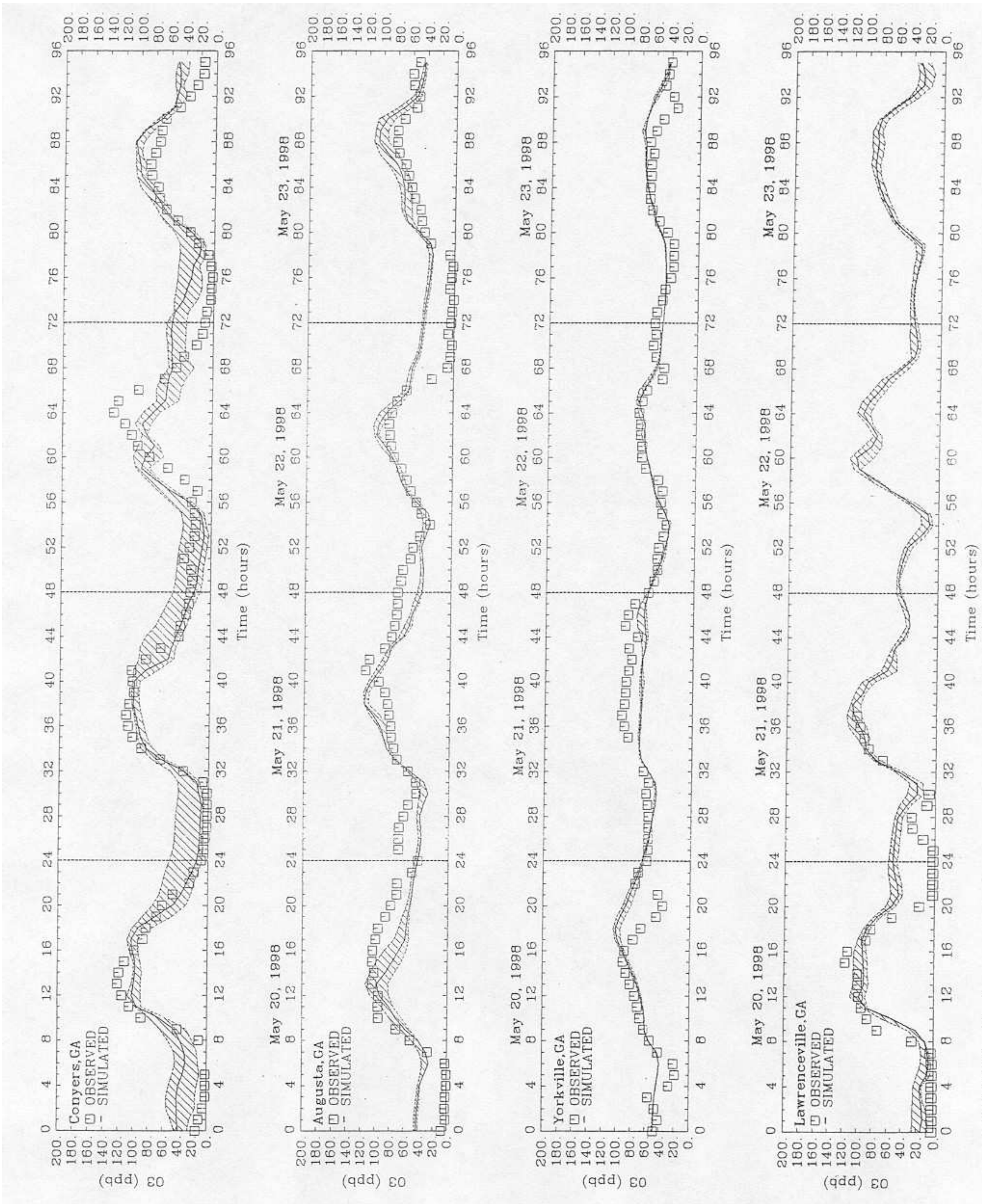

FIGURE 6-5a. Concluded.

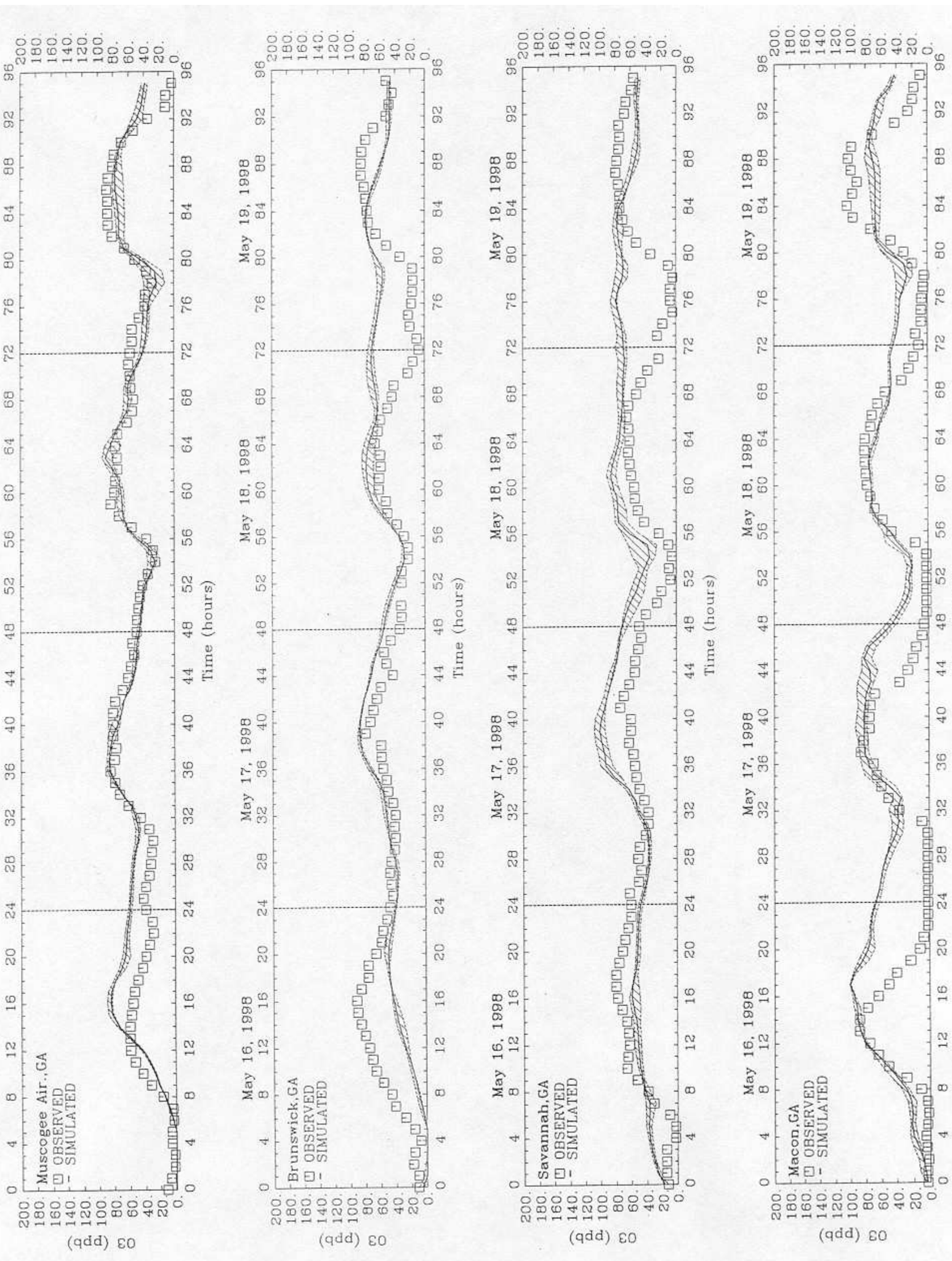

FIGURE 6-5b. Time-series plots comparing simulated and observed ozone concentrations for 16 – 19 May 1998: Other (GA) monitoring sites.

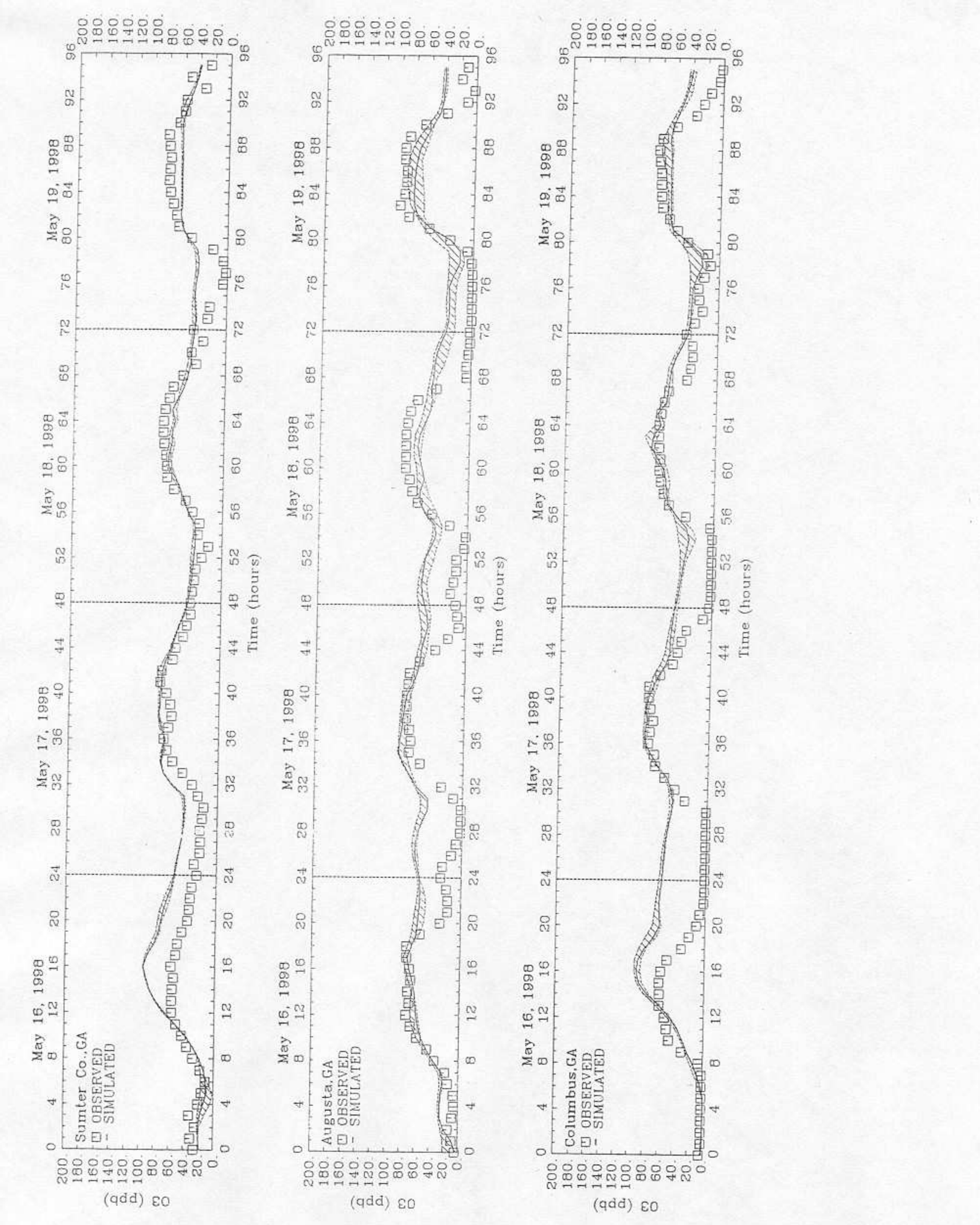

FIGURE 6–5b. Continued.

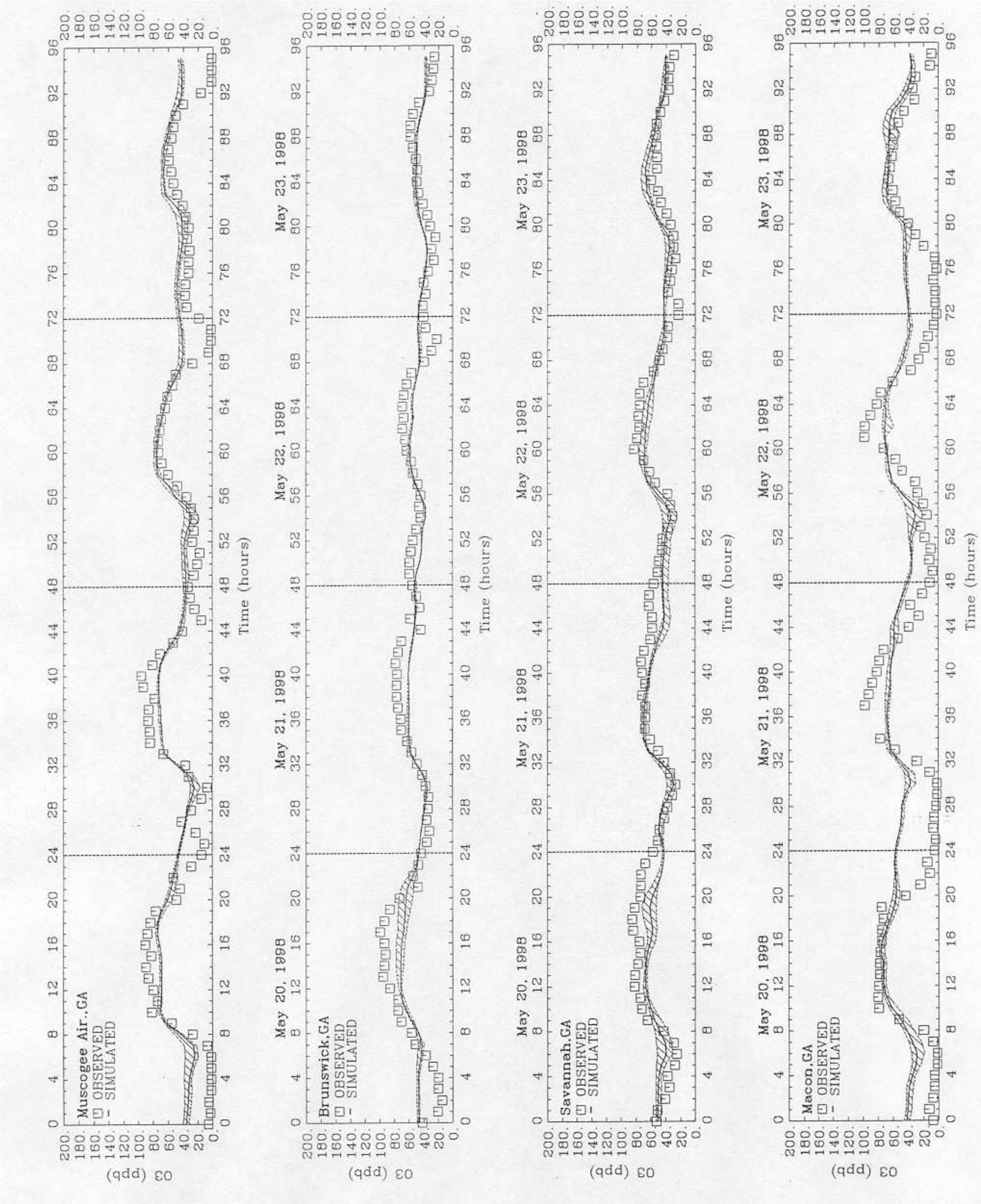

FIGURE 6-5b. Time-series plots comparing simulated and observed ozone concentrations for 20 – 23 May 1998: Other (GA) monitoring sites.

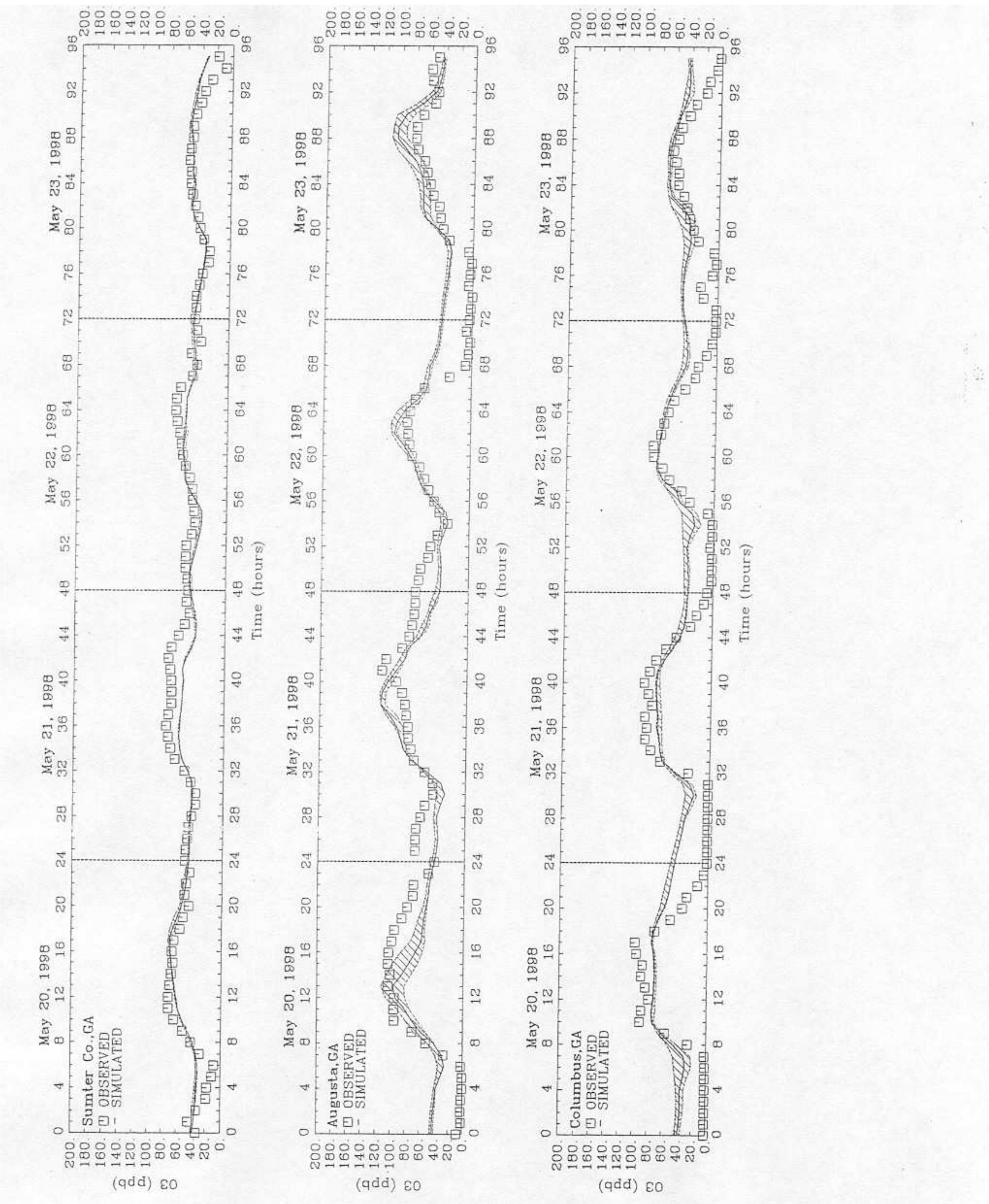

FIGURE 6-5b. Concluded.

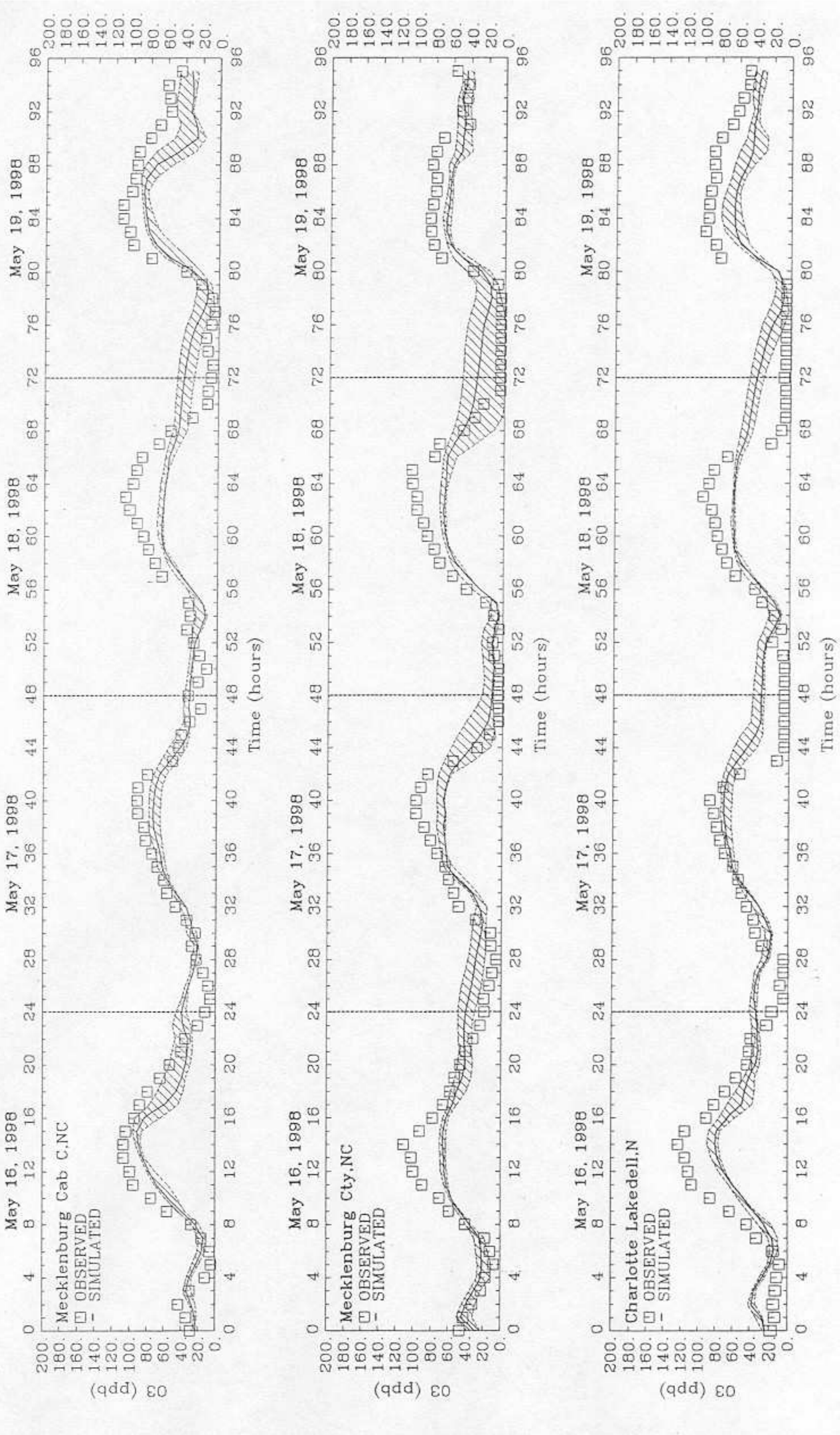

FIGURE 6-6a. Time-series plots comparing simulated and observed ozone concentrations for 16 – 19 May 1998: Charlotte (NC) monitoring sites.

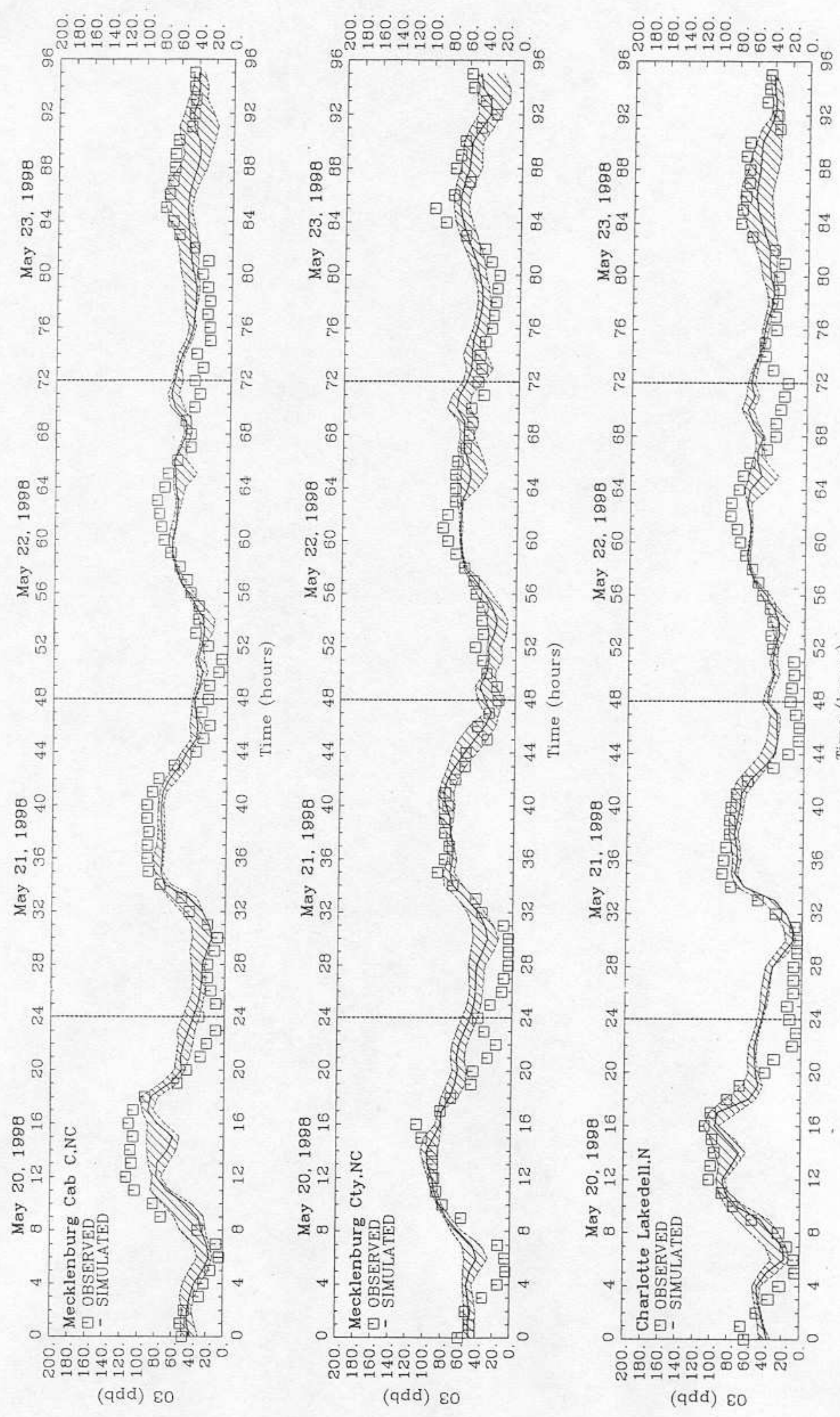

FIGURE 6-6a. Time-series plots comparing simulated and observed ozone concentrations for 20 - 23 May 1998: Charlotte (NC) monitoring sites.

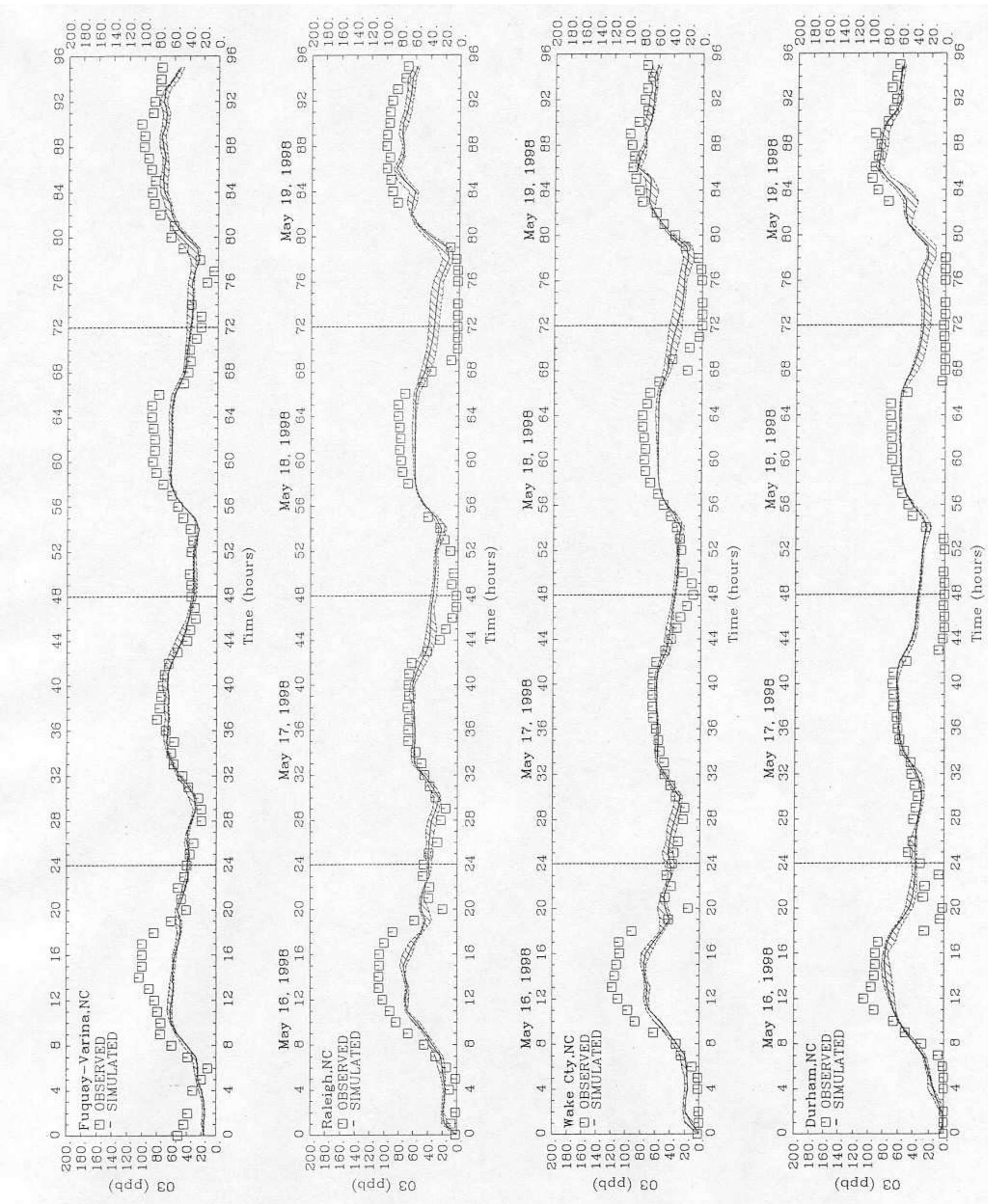

FIGURE 6-6b. Time-series plots comparing simulated and observed ozone concentrations for 16 – 19 May 1998: Raleigh-Durham (NC) monitoring sites.

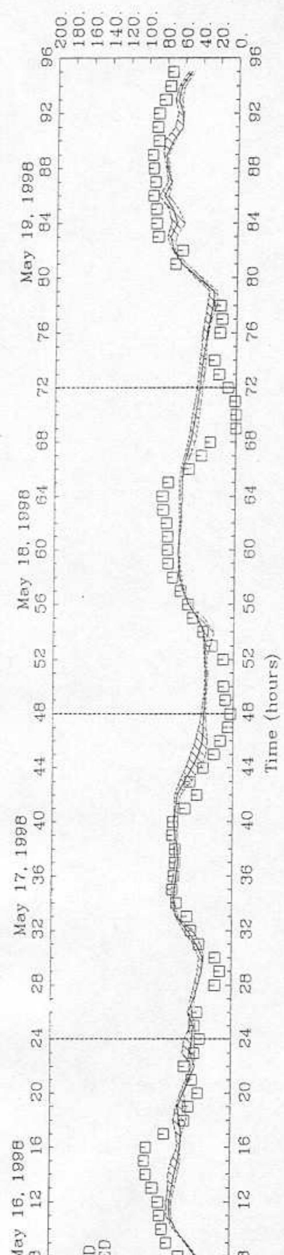

FIGURE 6-6b. Continued.

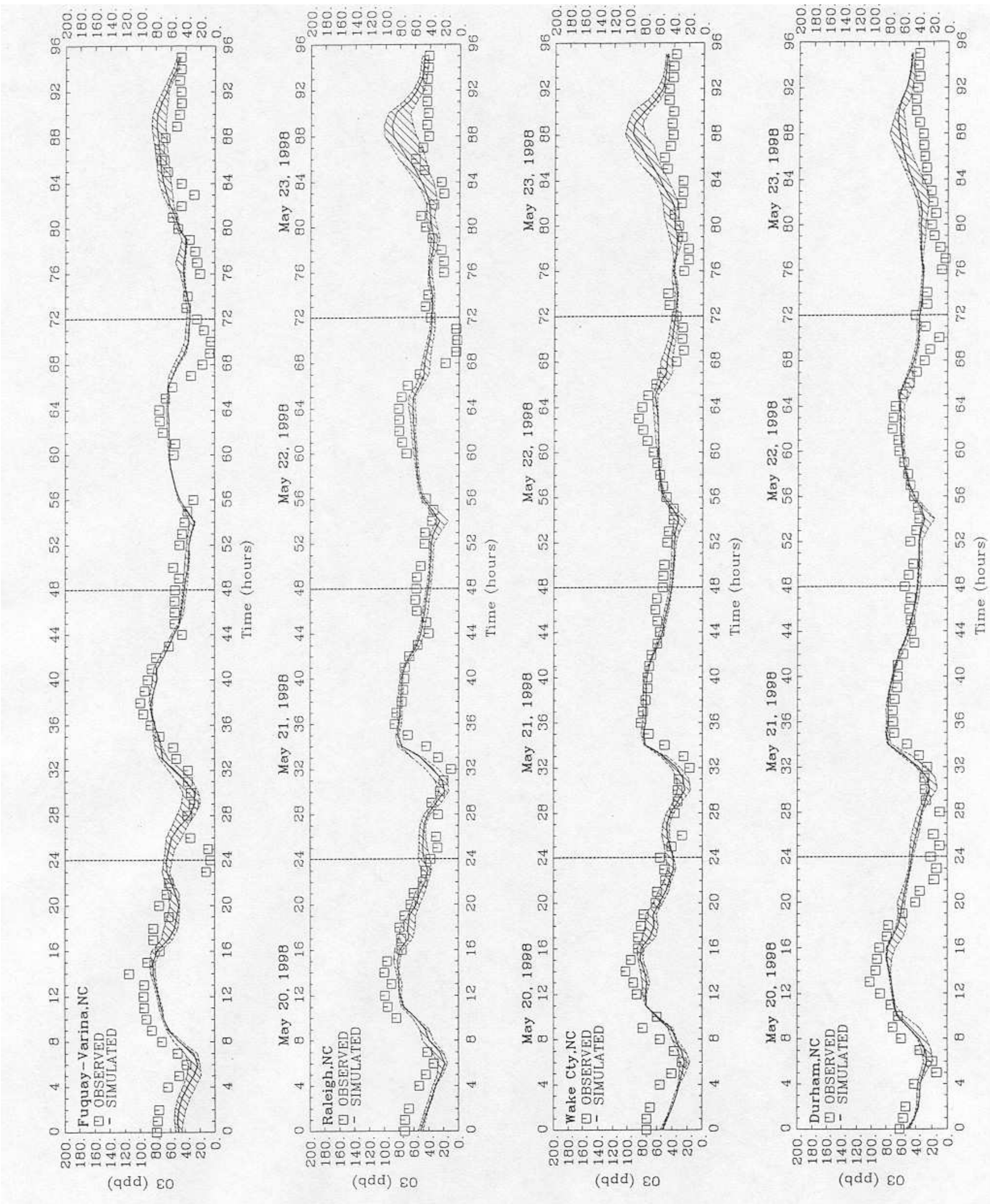

FIGURE 6-6b. Time-series plots comparing simulated and observed ozone concentrations for 20 – 23 May 1998: Raleigh-Durham (NC) monitoring sites.

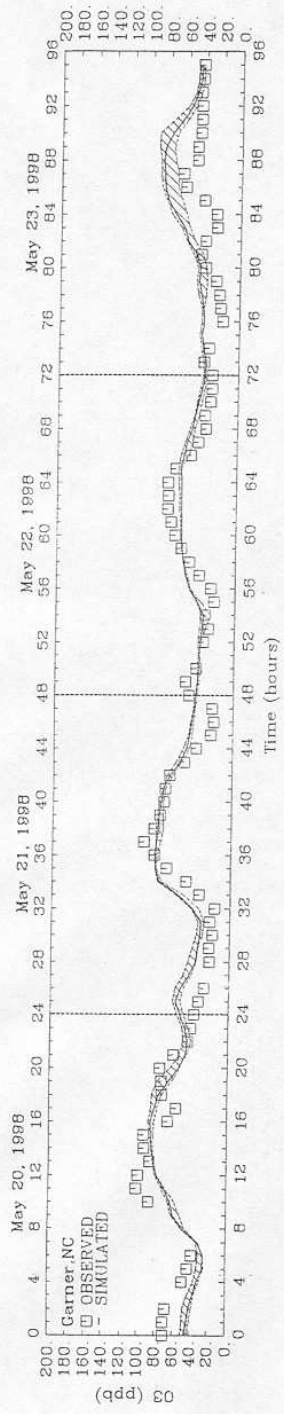

FIGURE 6–6b. Concluded.

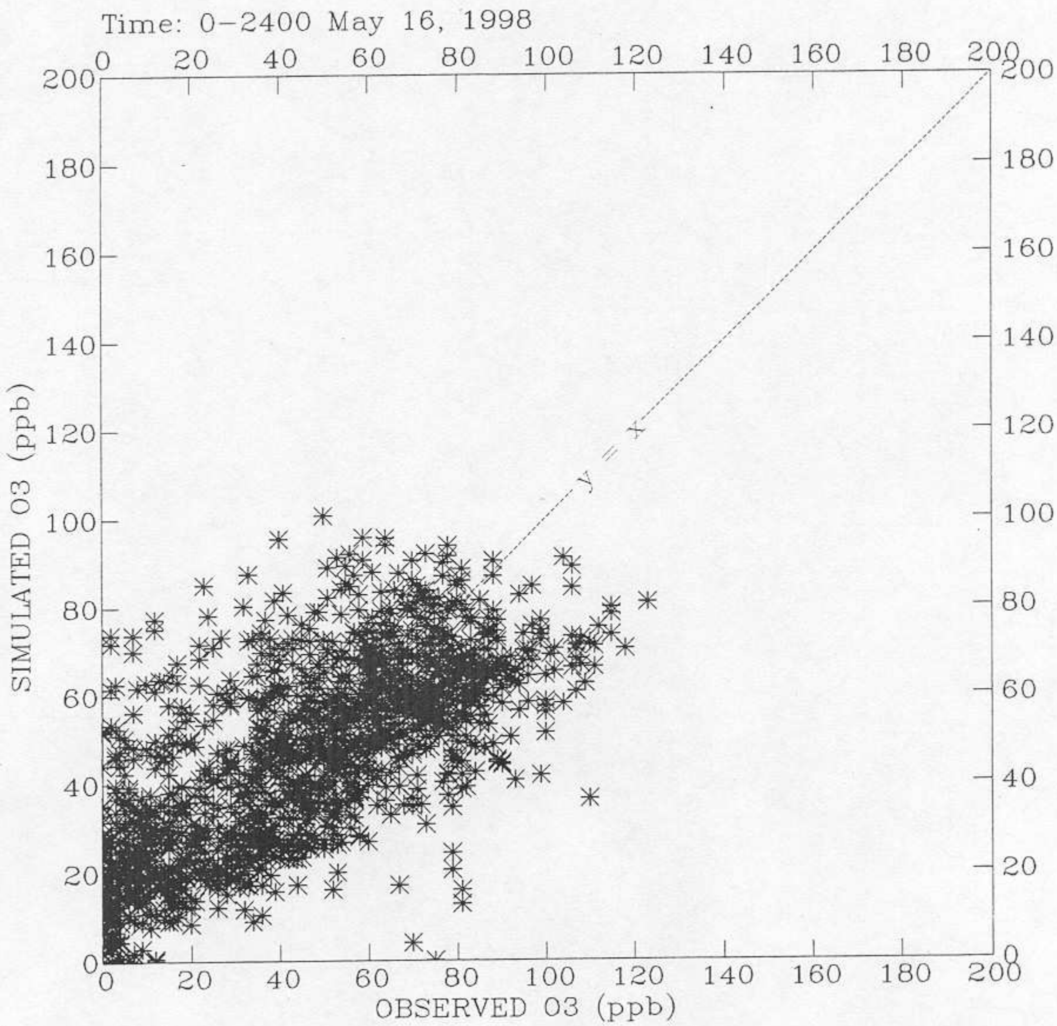

FIGURE 6-7a. Scatter plot comparing hourly simulated and observed ozone concentrations (ppb) for monitoring sites in Grid 3: 16 May 1998.

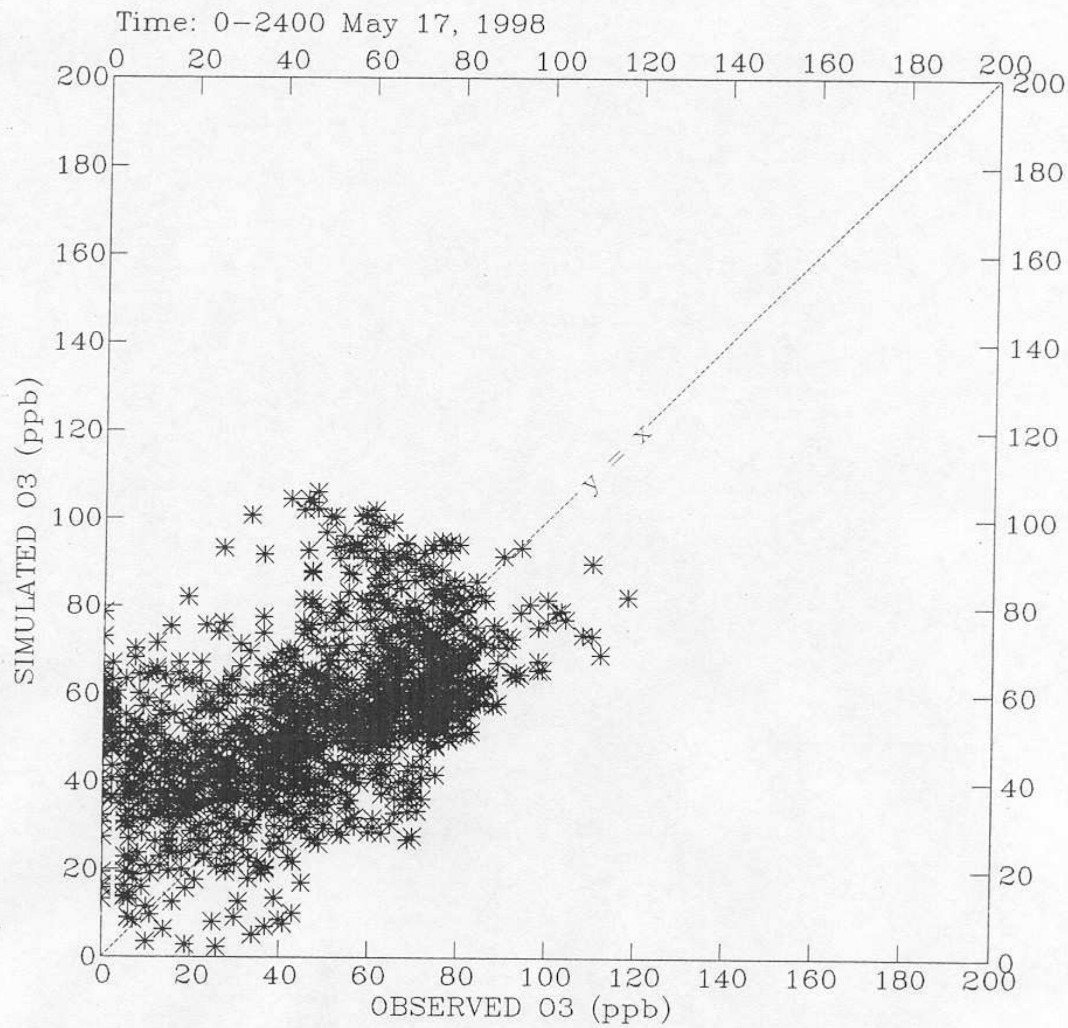

FIGURE 6-7b. Scatter plot comparing hourly simulated and observed ozone concentrations (ppb) for monitoring sites in Grid 3: 17 May 1998.

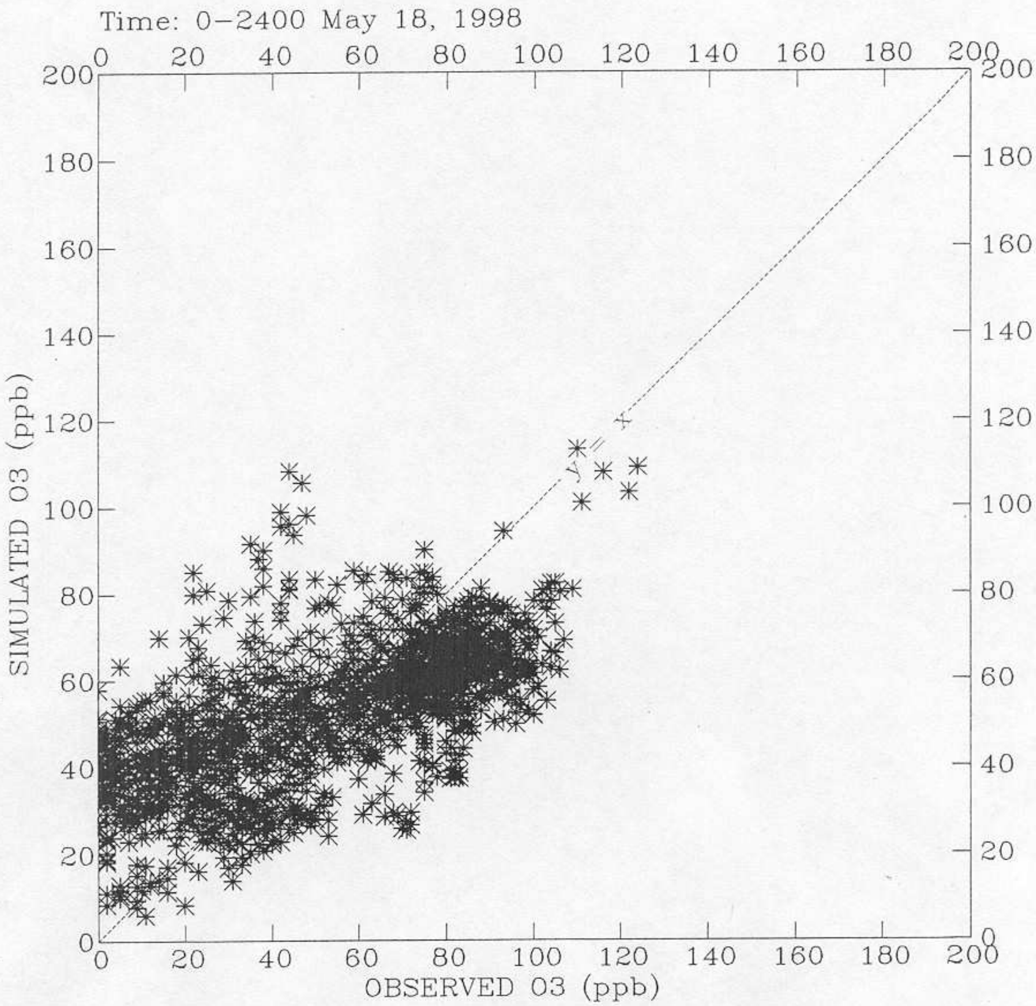

FIGURE 6−7c. Scatter plot comparing hourly simulated and observed ozone concentrations (ppb) for monitoring sites in Grid 3: 18 May 1998.

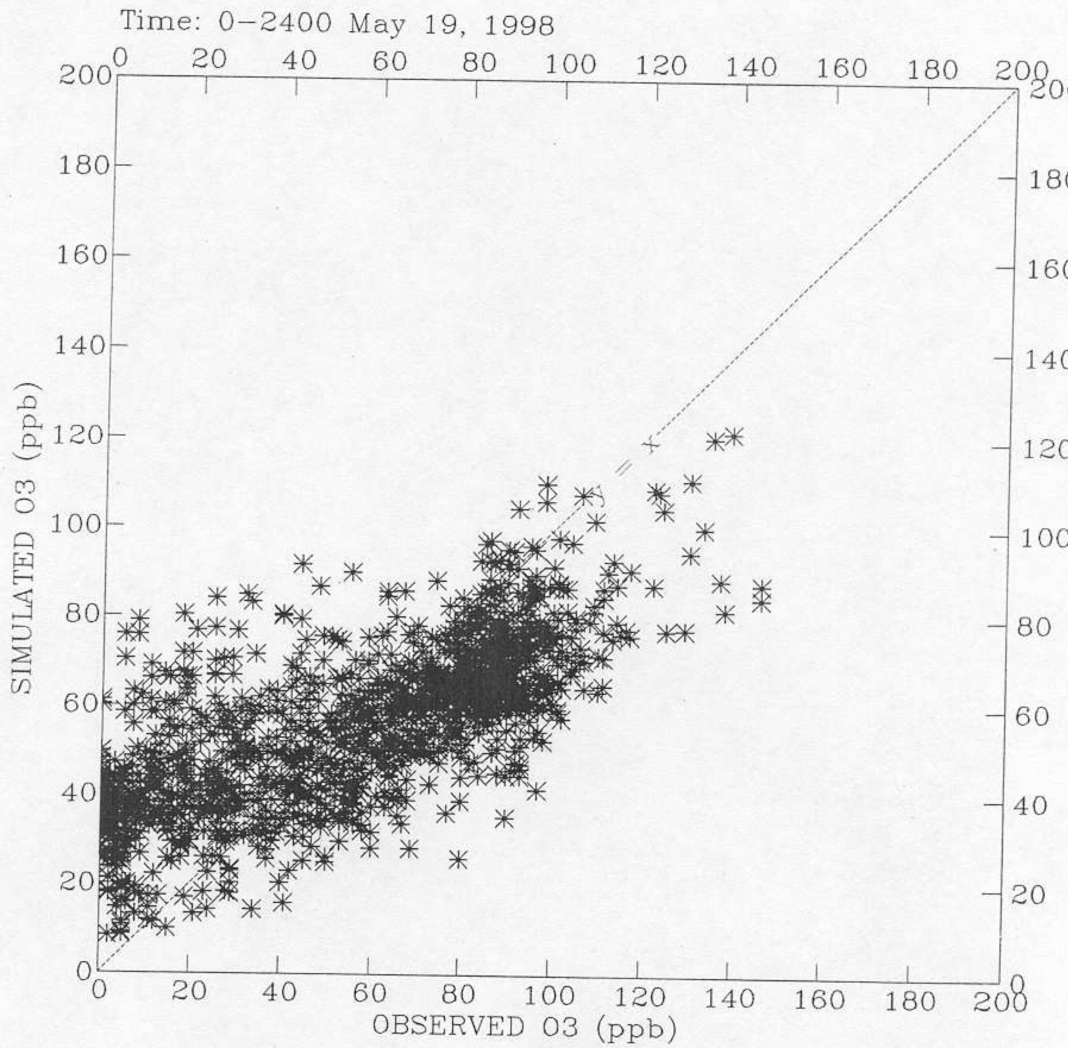

FIGURE 6-7d. Scatter plot comparing hourly simulated and observed ozone concentrations (ppb) for monitoring sites in Grid 3: 19 May 1998.

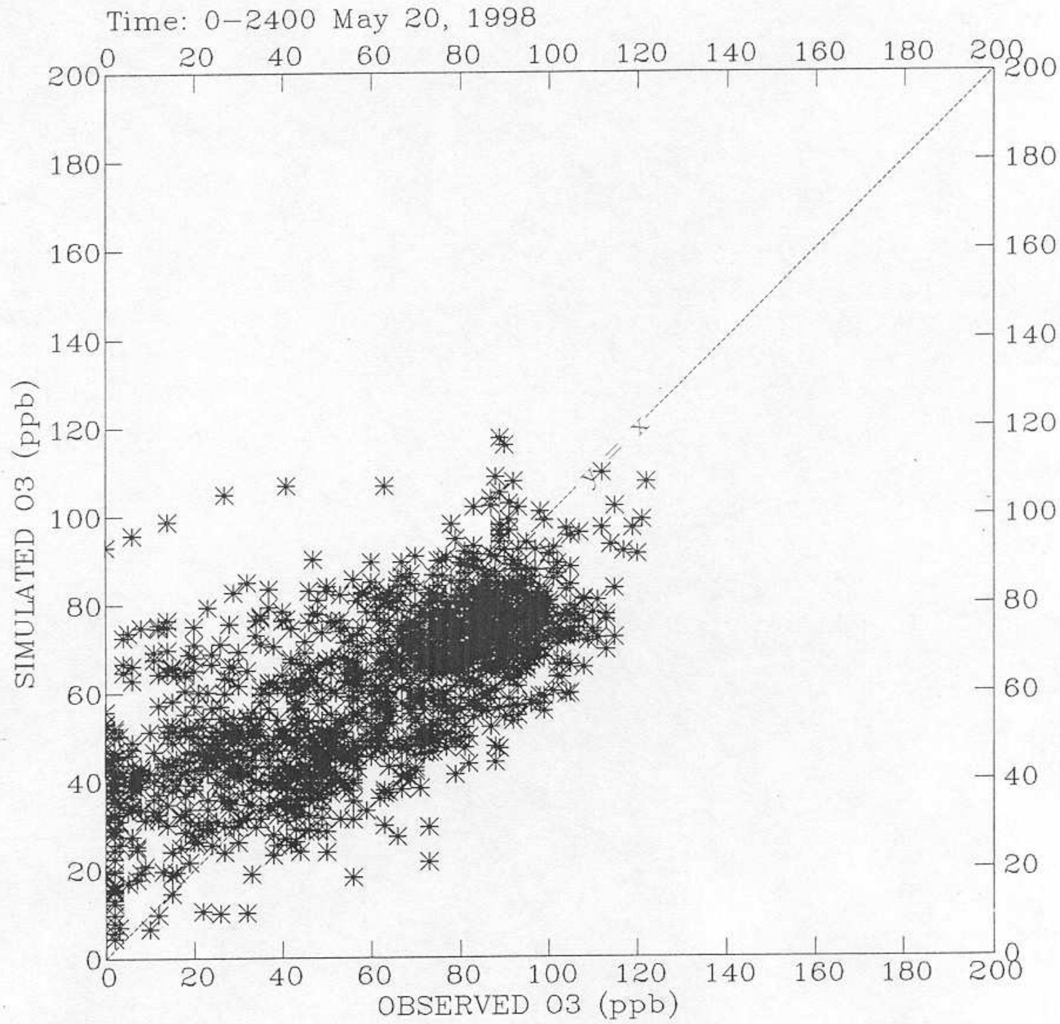

FIGURE 6-7e. Scatter plot comparing hourly simulated and observed ozone concentrations (ppb) for monitoring sites in Grid 3: 20 May 1998.

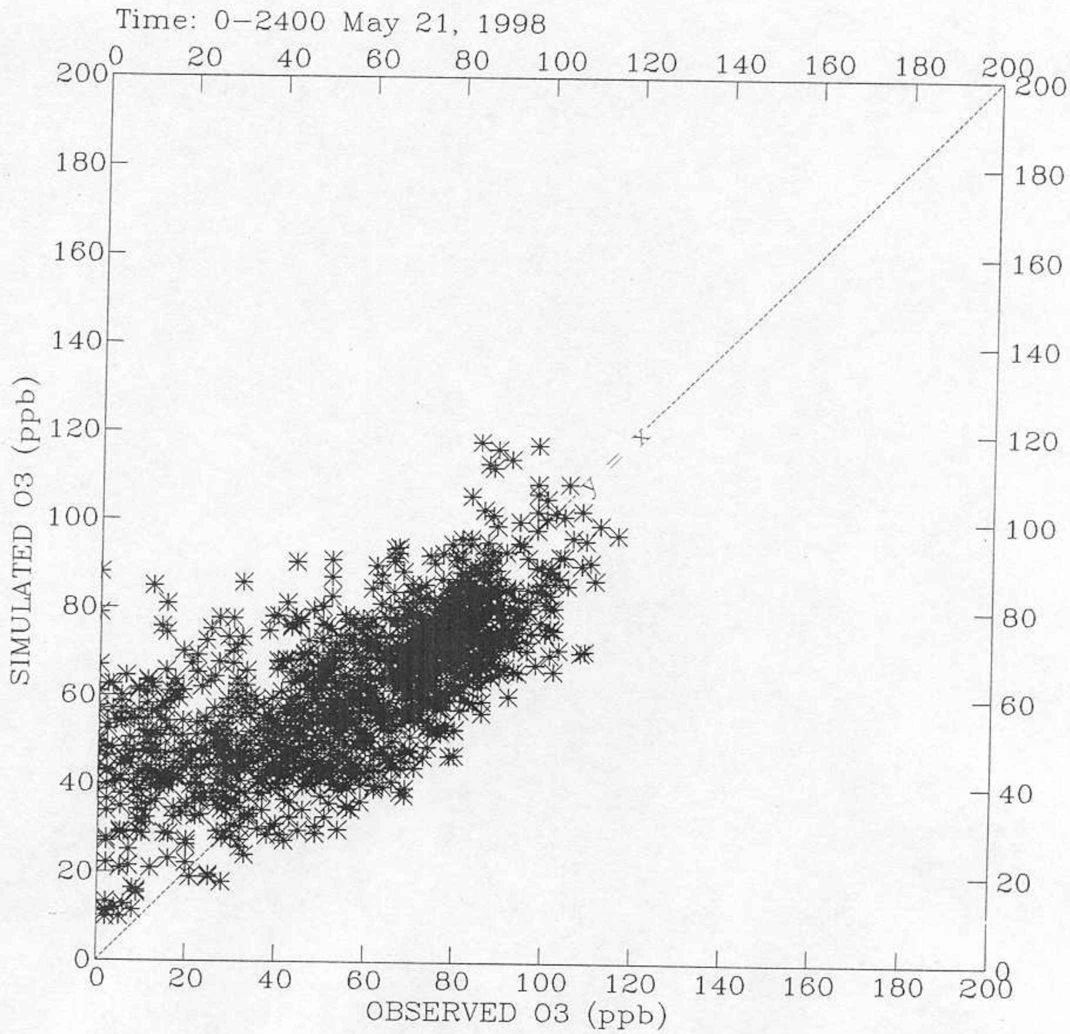

FIGURE 6–7f. Scatter plot comparing hourly simulated and observed ozone concentrations (ppb) for monitoring sites in Grid 3: 21 May 1998.

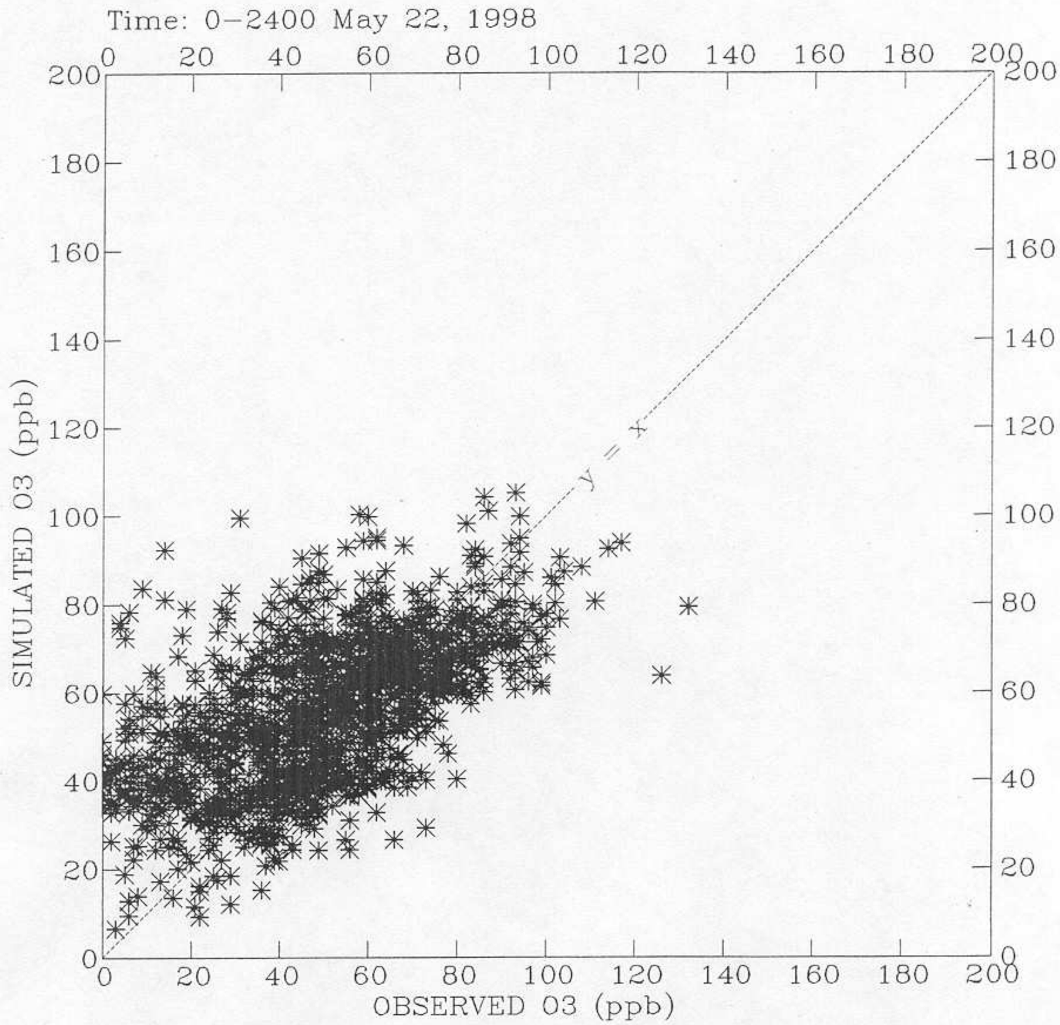

FIGURE 6-7g. Scatter plot comparing hourly simulated and observed ozone concentrations (ppb) for monitoring sites in Grid 3: 22 May 1998.

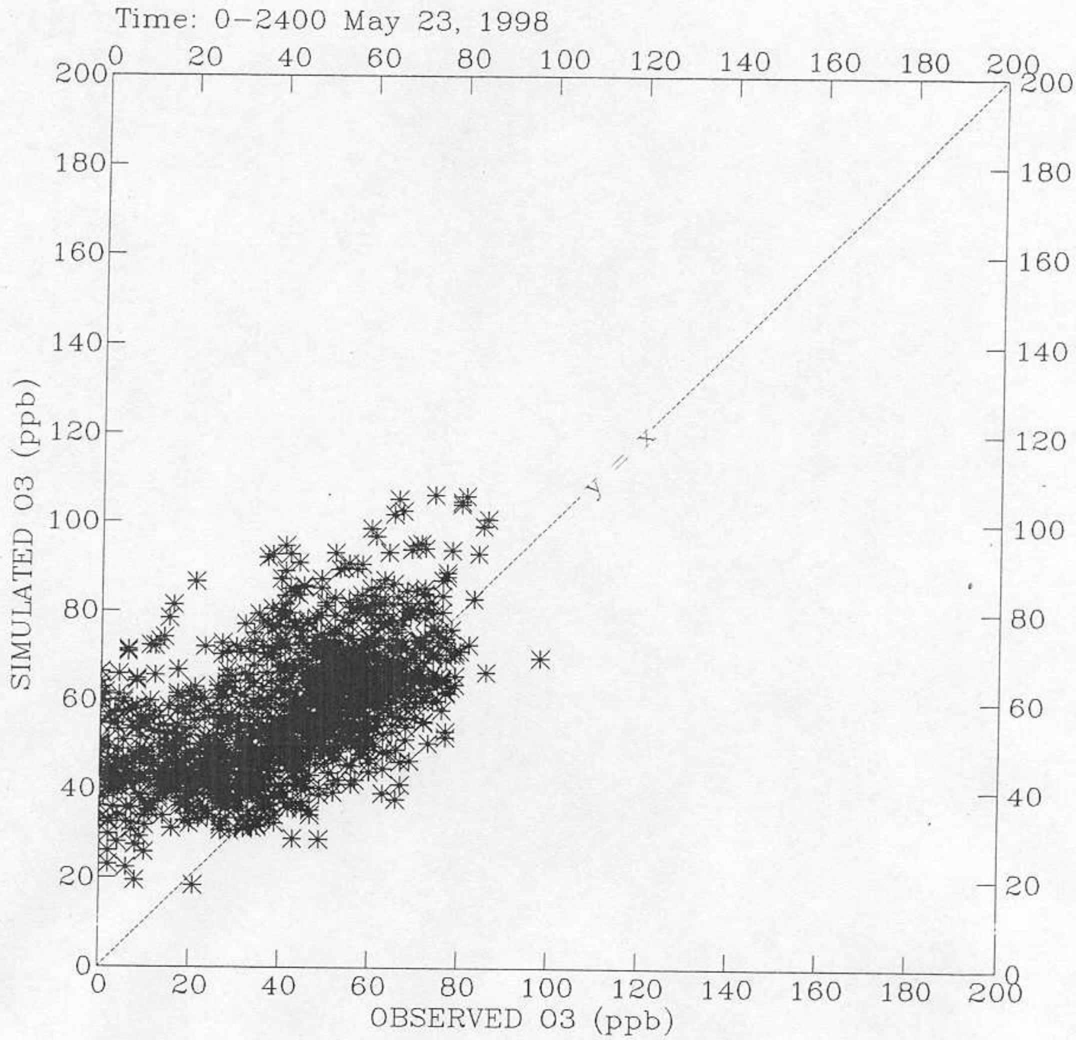

FIGURE 6-7h. Scatter plot comparing hourly simulated and observed ozone concentrations (ppb) for monitoring sites in Grid 3: 23 May 1998.

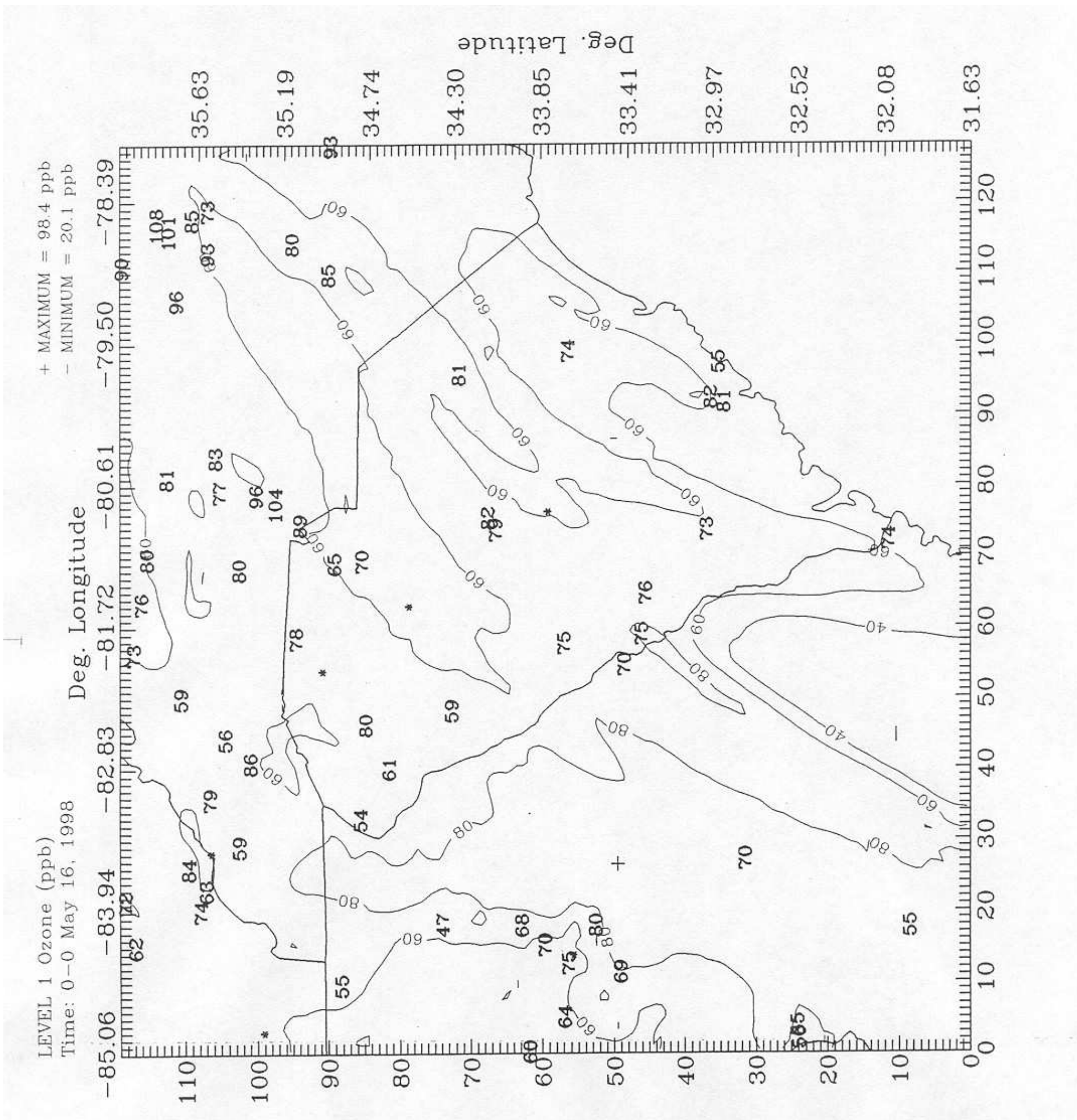

FIGURE 6-8a. Daily maximum UAM-V simulated 8-hour ozone concentration (ppb) for SCDHEC Grid 3: 16 May 1998. Observed values are shown in bold.

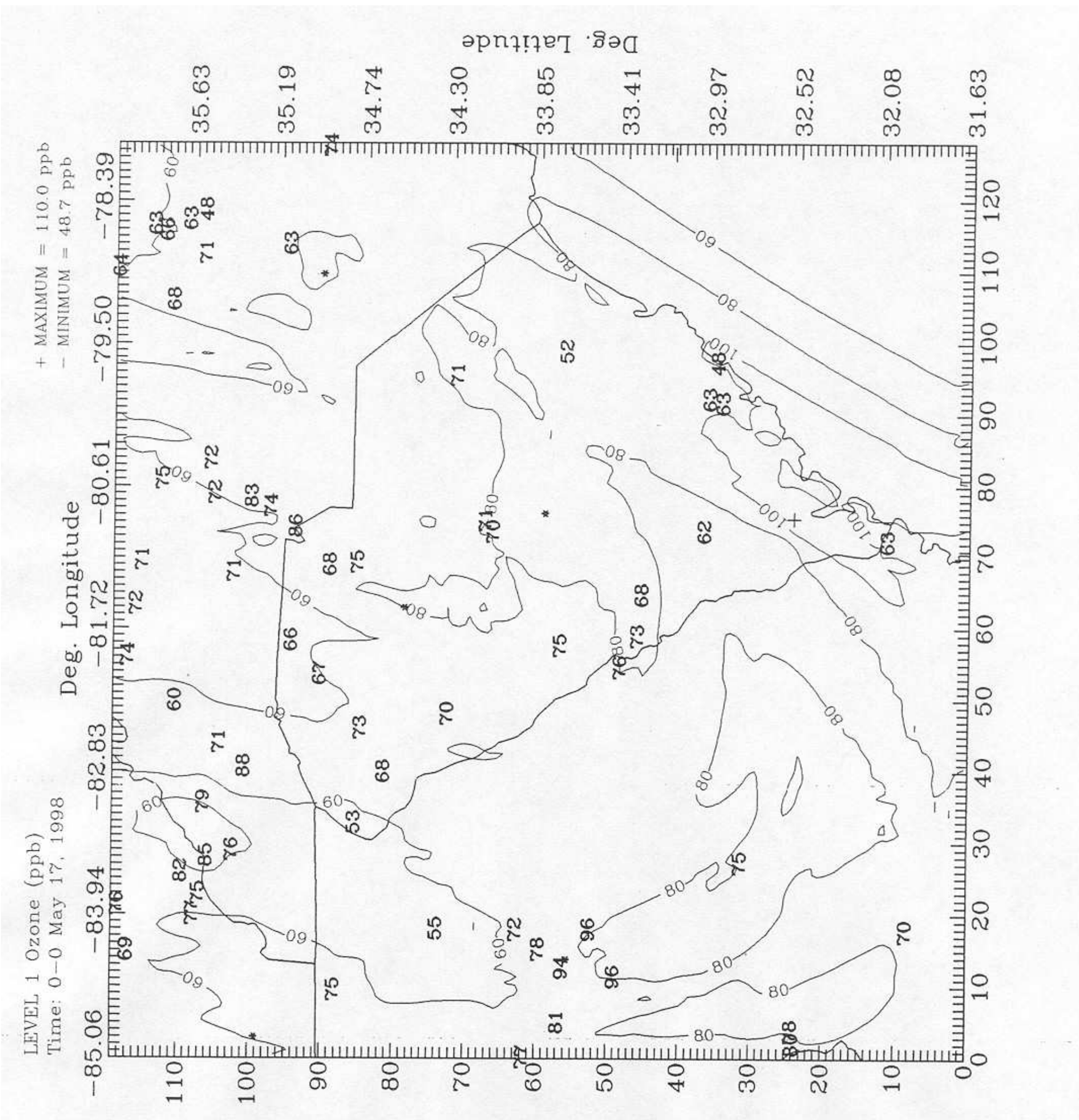

FIGURE 6-8b. Daily maximum UAM-V simulated 8-hour ozone concentration (ppb) for SCDHEC Grid 3: 17 May 1998. Observed values are shown in bold.

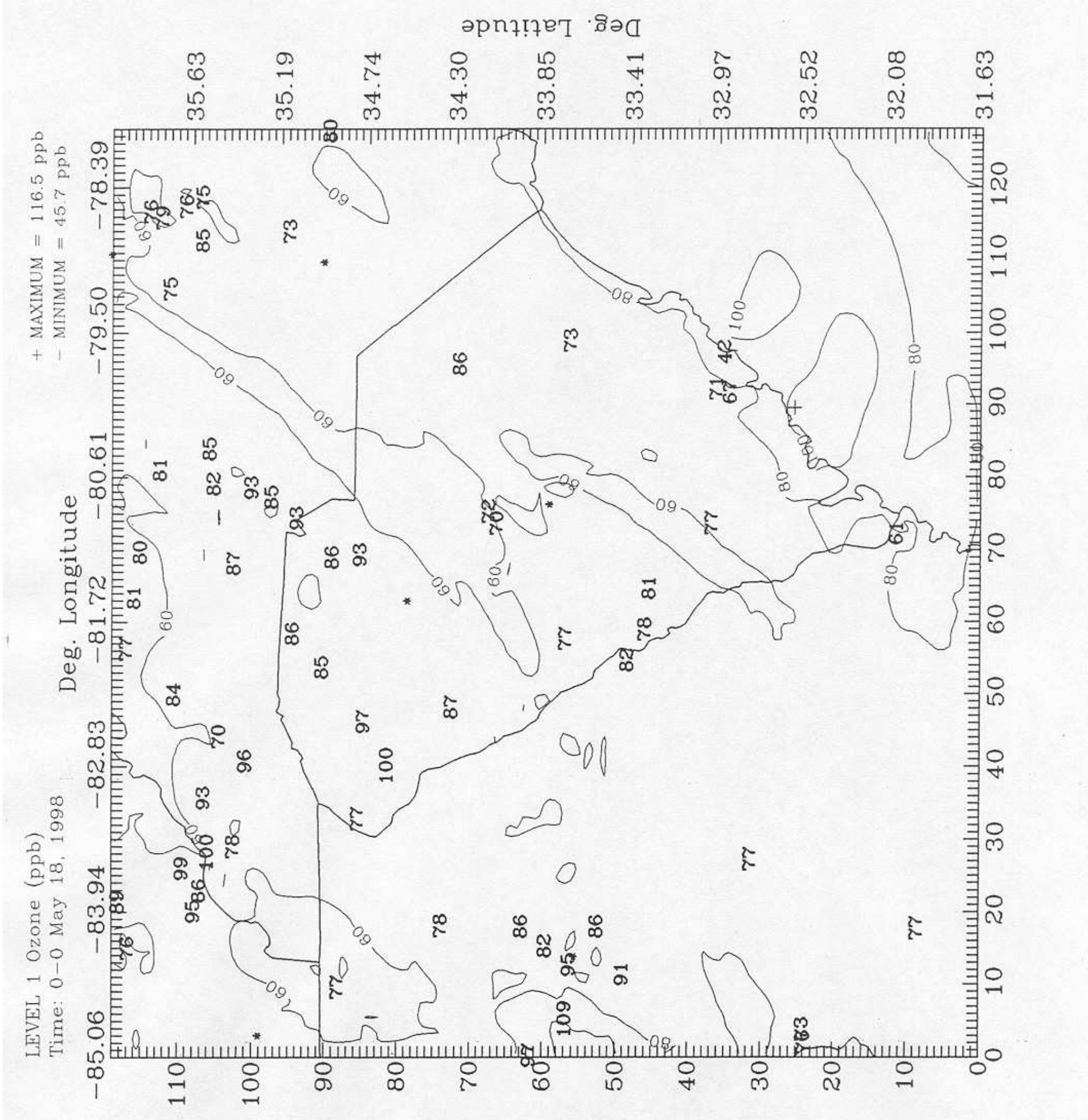

FIGURE 6-8c. Daily maximum UAM-V simulated 8-hour ozone concentration (ppb) for SCDHEC Grid 3: 18 May 1998. Observed values are shown in bold.

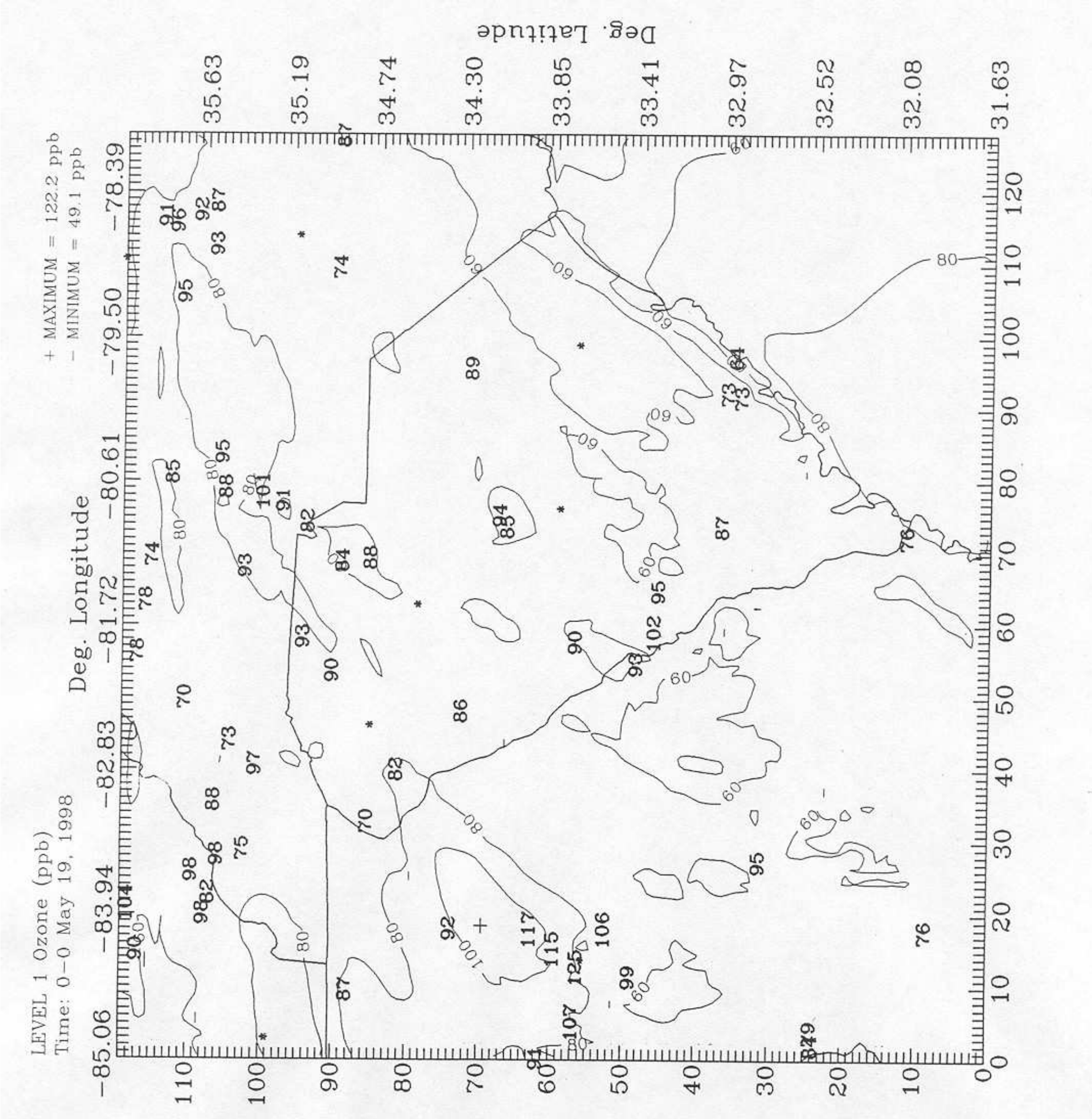

FIGURE 6-8d. Daily maximum UAM-V simulated 8-hour ozone concentration (ppb) for SCDHEC Grid 3: 19 May 1998. Observed values are shown in bold.

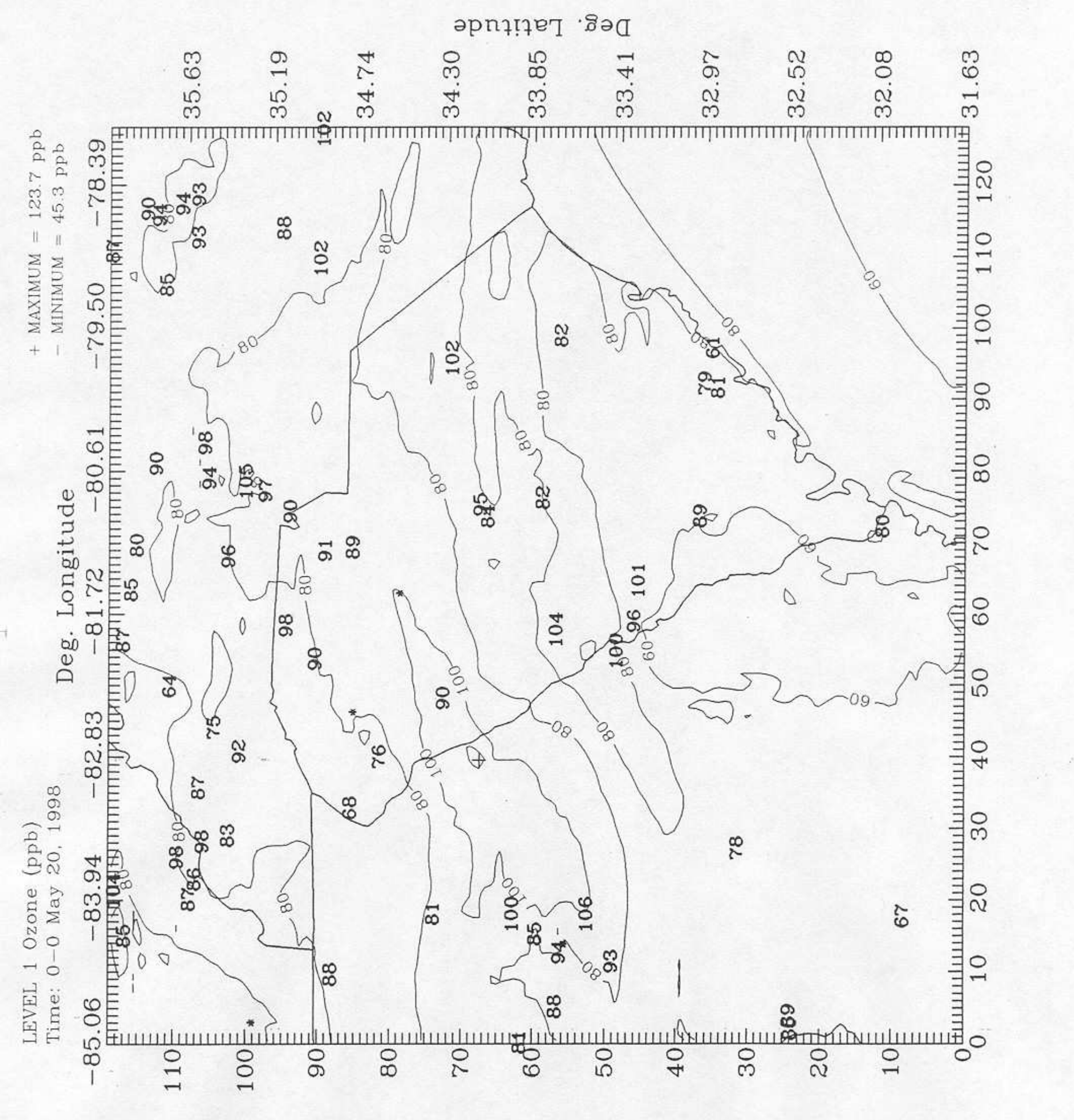

FIGURE 6-8e. Daily maximum UAM-V simulated 8-hour ozone concentration (ppb) for SCDHEC Grid 3: 20 May 1998. Observed values are shown in bold.

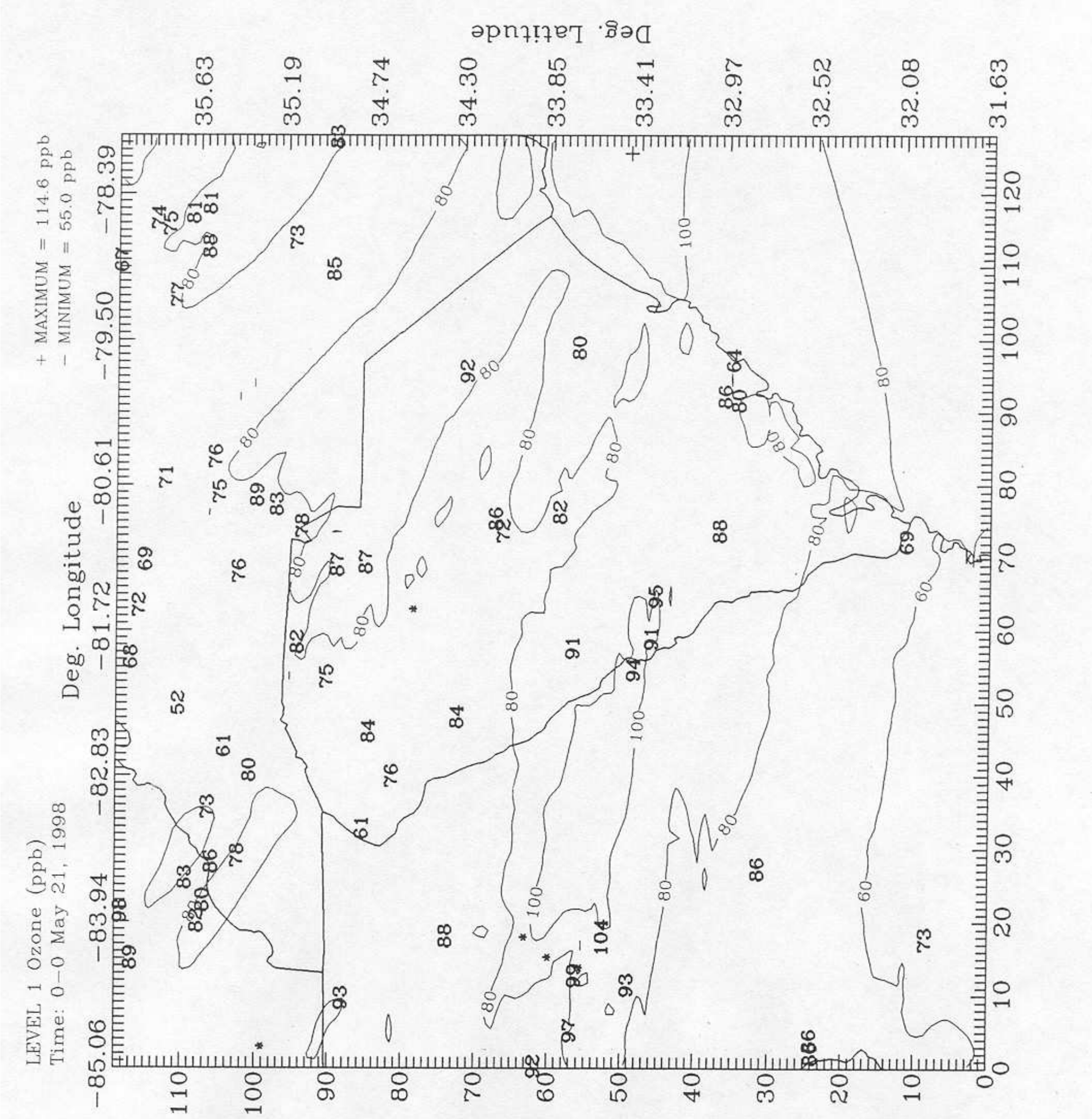

FIGURE 6-8f. Daily maximum UAM-V simulated 8-hour ozone concentration (ppb) for SCDHEC Grid 3: 21 May 1998. Observed values are shown in bold.

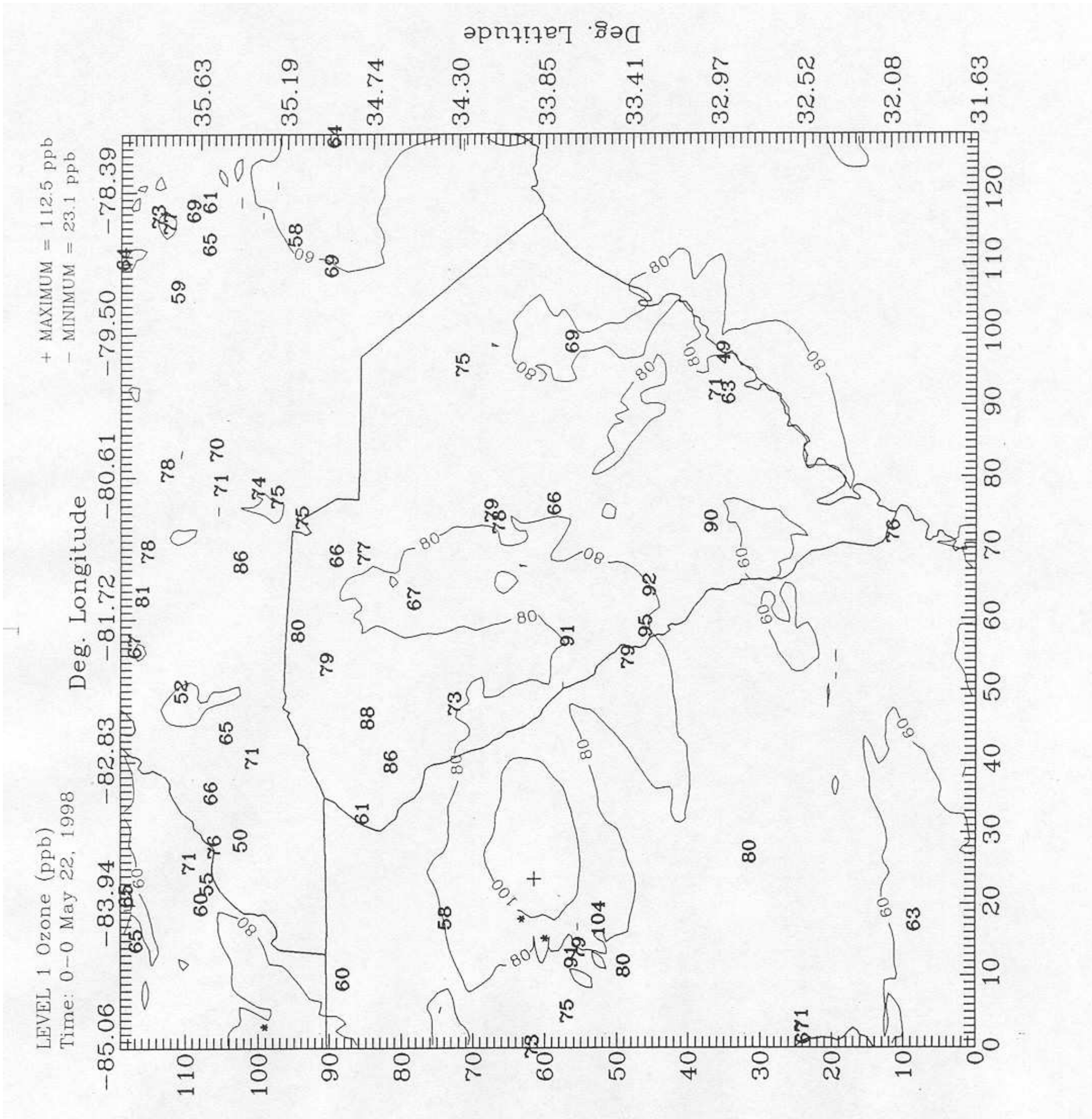

FIGURE 6-8g. Daily maximum UAM-V simulated 8-hour ozone concentration (ppb) for SCDHEC Grid 3: 22 May 1998. Observed values are shown in bold.

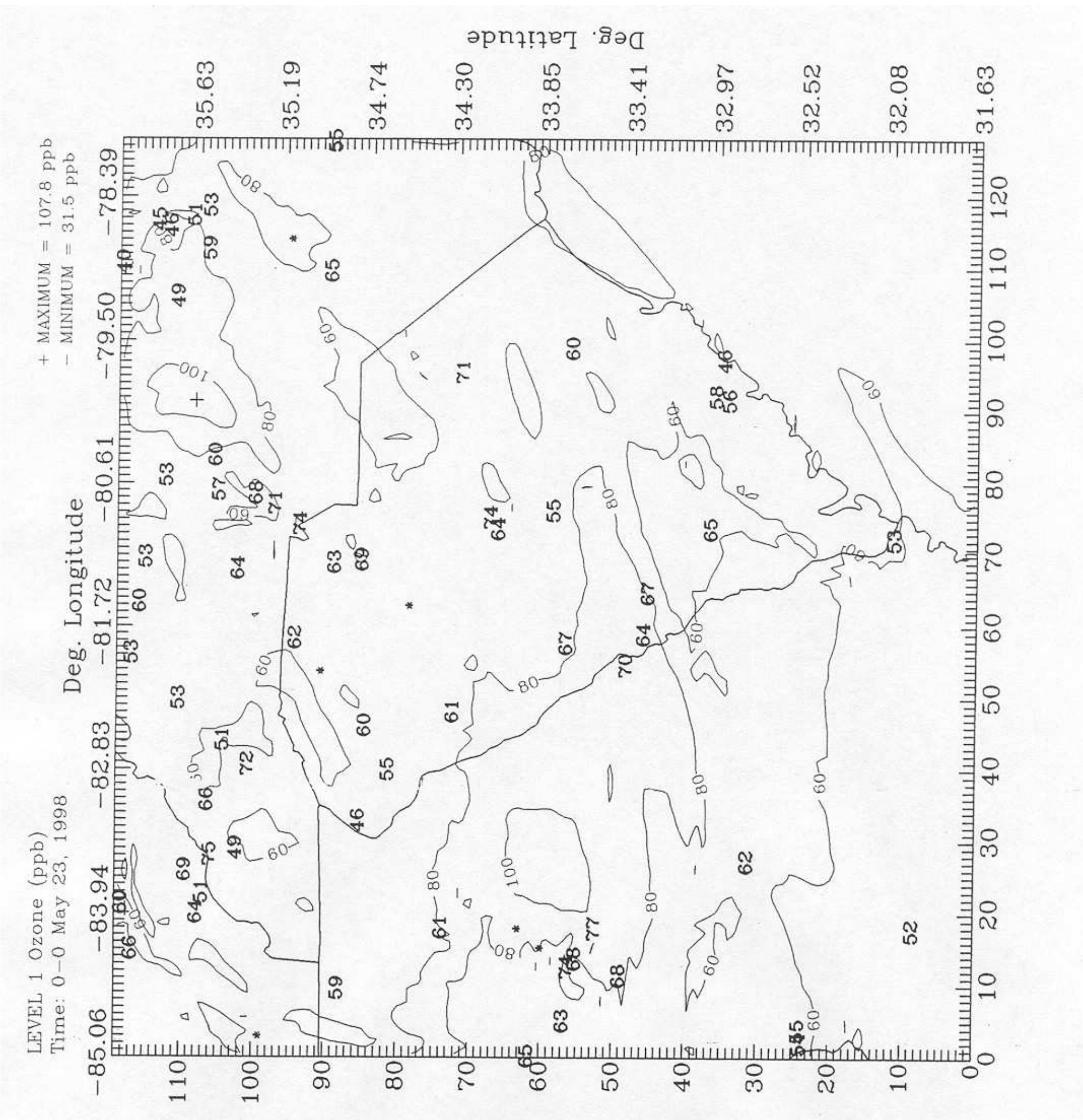

FIGURE 6-8h. Daily maximum UAM-V simulated 8-hour ozone concentration (ppb) for SCDHEC Grid 3: 23 May 1998. Observed values are shown in bold.

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VII. Future-Year Modeling

The SC DHEC modeling analysis included the application of the UAM-V modeling system for future years of 2007, 2012, and 2017. A future year modeling analysis of 2017 is included to provide an indication of the impact of the Early Action Compact process on future year ozone levels. This section presents the preparation of the future-year emission inventories and the results of the future-year modeling exercise.

Before presenting the future-year emissions and modeling results, we first introduce the ACCESS™ Database for Visualizing and Investigating Strategies for Ozone Reduction (ADVISOR) analysis tool that was used throughout the future-year modeling exercises to examine and display the emissions and modeling results.

For ease of reading, all figures follow the text in this section.

A. Overview of ADVISOR

The SC DHEC ADVISOR is an interactive database tool that contains information for review, comparison, and assessment of the SC DHEC base-case and future-year UAM-V simulations. The database contains emissions and simulated ozone concentrations, as represented by several different metrics, for all of the SC DHEC UAM-V modeling grids. The ADVISOR database also supports application of draft EPA 8-hour ozone attainment demonstration procedures, including the calculation of site-specific relative reduction factors and estimated design values.

The SC DHEC ADVISOR metrics include:

- Maximum 1-hour ozone concentration (ppb).
- Maximum 8-hour ozone concentration (ppb).
- Number of grid cell · hours with maximum 1-hour ozone concentrations ≥ 125 ppb.
- Number of grid cells with maximum 8-hour ozone concentrations ≥ 85 ppb.
- Total ozone exposure (ppb · grid cell · hour).
- 1-hour exceedance ozone exposure (ppb · grid cell · hour) for 1-hour ozone concentrations ≥ 125 ppb.
- 8-hour exceedance ozone exposure (ppb · grid cell) for 8-hour ozone concentrations ≥ 85 ppb.
- Population[4] exposure (ppb · person hours) to 1-hour ozone concentrations ≥ 125 ppb.
- Population exposure (ppb · person) to 8-hour ozone concentration ≥ 85 ppb.
- Total emissions (NO_x, VOC).

Options for displaying the metrics include:

- Value.
- Difference (relative to a selected base simulation such as the future-year baseline).

[4] Population estimates are based on 1990 U.S. Census data.

- Percentage difference.
- Effectiveness (change in ozone metric relative to the change in emissions[5], again relative to a selected base simulation).
- Relative reduction factor.
- Estimated design value.

Geographies consisting of grids, subregions, and monitoring sites include:

- Grid 1 (36 km grid spacing)
- Grid 2 (12 km grid spacing)
- Grid 3 (4 km grid spacing)
- State of South Carolina
- Anderson-Greenville-Spartanburg MSA
- Anderson County
- Greenville County
- Spartanburg County
- Columbia MSA
- Richland County
- Charleston MSA
- Florence-Darlington area
- Darlington County
- Florence County
- Lancaster County
- Myrtle Beach (Horry County)
- Orangeburg County
- Rock Hill (York County)
- Sumter County
- Augusta, GA MSA
- Aiken County
- Atlanta, GA 13-county NAA
- Macon, GA MSA
- Savannah, GA MSA

[5] The change in emissions can be calculated for a different geographical area than the change in ozone metric.

- Charlotte, NC MSA
- Hickory, NC MSA
- Raleigh, NC MSA
- Winston-Salem, NC MSA
- All monitoring sites within Grid 3

An estimate of the modeling system noise, as calculated for certain metrics, is also included as a display option in the ADVISOR database. This feature is intended to provide perspective on the meaningfulness of the simulated ozone reductions.

In the remainder of this section and the following section, a few key metrics and options from the list above are used extensively to present and compare the simulation results:

- Maximum 8-hour ozone concentration is the simulated maximum 8-hour average ozone concentration for a given "geography" (grid, subregion, or monitoring site) and time period. The units are ppb.
- 8-hour ozone exceedance exposure is a measure of the "excess" simulated 8-hour concentration that is greater than 85 ppb. The difference between the maximum simulated 8-hour ozone concentration and 85 ppb is calculated and summed for each grid cell and day within a specified grid or subregion and time period.
- Effectiveness is used to characterize the change in ozone per change in emissions (i.e., per ton of NO_x or VOC reduced). The units are those for the selected ozone metric per ton.
- The estimated design value is an estimate of the 8-hour ozone design value for a selected monitoring site and future-year scenario. It is calculated as the current design value multiplied by a relative reduction factor (RRF), where the RRF is the ratio of the future-year-scenario to base-year 8-hour ozone concentration in the vicinity of the monitoring site. This metric will primarily be used to discuss the results from a preliminary application of the draft 8-hour ozone attainment demonstration procedures in the next section of this report. The units are in ppb.

The SC DHEC ADVISOR is available as an electronic attachment to this report (see Section 10).

B. Future-Year Emissions Inventory Preparation

This section discusses the methodologies followed in preparing the future-year baseline emission inventories for 2007, 2012, and 2017.

Use of the Bureau of Economic Analysis (BEA) Growth Factors for the South Carolina EAC Modeling Analysis

The projection of a base year emission inventory to a future year requires the use of economic growth factors. These are applied to the various industrial sectors and source categories to reflect expected future growth (or decline) in industrial activity and resulting emissions. There are five sets of factors available for use in projecting emission inventories for modeling. The Bureau of Economic Analysis (BEA) provides three such sets, while another two sets are available in EPA's Economic Growth Analysis System (EGAS). For ozone SIP modeling exercises, EPA guidance does not state a preference of which set to use, but does recommend that local growth information be considered in the selection and use of such factors. The BEA projection series provides state-level personal earnings, employment, and gross state product (GSP - value added) data for selected years through the year 2045, and the projection factors are available at 2-digit SIC code level for point sources and 4-digit ASC code level for area sources. The latest set of growth factors provided by BEA was issued in 1995; BEA no longer publishes growth factors. The EGAS system includes both BEA factors and two other sets of growth factors that purportedly provide more detailed information geographically and by source category. The EGAS provides the county-level growth factors for area sources at the 10-digit ASC code level, and growth factors for point sources at the 2-digit SIC code level with associated fuel type or 8-digit SCC code. The two sets of factors provided by EGAS are from the Bureau of Labor Statistics (BLS) and from Wharton Econometric Forecasting Associates (WEFA). Although the EGAS system purports to provide growth factors by county, for the State of South Carolina and all other surrounding states, all of the factors contained in the latest version of EGAS are the same for all counties within each state – there are no county-to-county differences.

For the South Carolina EAC modeling analysis, the future-year emission inventories for 2007, 2012, and 2017 were developed using economic growth factors provided by the BEA. Specifically, the state-specific GSP factors were used for South Carolina and all other states within the modeling domain. The selection of the BEA factors was not based on any assessment of the quality or accuracy of BEA vs. EGAS. EPA guidance does recommend that value added projections be used, and BEA's GSP factors are a measure of value added and a more complete measure of growth than BEA's earnings factors, which are only one component of GSP. The BEA GSP factors have been used recently by EPA in ozone and particulate matter modeling conducted to support national rulemaking for the Tier 2 engine and fuel sulfur standards, the non-road diesel engine rulemaking, the Clear Skies Initiative (CSI), and most recently, in the Interstate Air Quality Rule (IAQR) modeling analysis.

Area Source Emissions

Area Source Projection

The future-year growth estimates for area sources were based on Bureau of Economic Analysis (BEA) projections of Gross State Product (GSP) for all states. The BEA projections were applied at the 4-digit AIRS Source Category (ASC) level for area sources, and represent growth between the base year and future year (2007, 2012, and 2017).

Area Source Controls

For fuel combustion sources, energy adjustment factors, which were developed from DOE publication "Annual Energy Outlook 1999," were applied to the baseline emissions to account for increases in fuel and process efficiency in 2007, 2012, and 2017.

VOC controls were applied to area sources using information provided by EPA. The controls include federal initiatives, such as VOC content limits for consumer solvents; Title III maximum achievable control technology (MACT) assumptions; and Title I reasonably available control technology (RACT) assumptions that were not applied in the 1998 base year inventory. These controls are presented in Table 7-2.

Table 7-3 shows the VOC and CO controls applied for residential wood combustion, and Table 7-4 lists the control efficiencies applied to account for VOC reductions associated with onboard vapor recovery systems and Stage II controls at gasoline service stations. Under Title I of the CAA, serious and above ozone nonattainment areas are required to implement Stage II (at-the-nozzle) vapor recovery systems. Control efficiencies for VOC Stage II are provided for counties required to have Stage II VOC controls and for counties not required to have Stage II VOC controls.

All emissions due to open burning were eliminated for the 45 counties in Northern Georgia by a seasonal ban (Georgia Department of Natural Resources Environmental Protection Division: Georgia's State Implementation Plan for the Atlanta Ozone Non-attainment Area, July 17, 2001). The 45 counties are 13 non-attainment and 32 additional counties (eliminated both prescribed and slash burning for Bartow, Carroll, Hall, Newton, Spalding and Walton counties; and eliminated slash burning for Banks, Barrow, Butts, Chattooga, Clarke, Dawson, Floyd, Gordon, Haralson, Heard, Jackson, Jasper, Jones, Lamar, Lumpkin, Madison, Meriwether, Monroe, Morgan, Oconee, Pickens, Pike, Polk, Putnam, Troup and Upson counties).

Emissions from burning of yard waste, municipal solid waste, and land clearing waste are estimated for a given county or state using a variety of formulas, emission factors, and other assumptions. Estimates of the tonnage of waste burned, obtained from local solid waste, air quality, forest service, agricultural, or health agencies or fire departments are combined with appropriate emission factors to calculate emissions. Large uncertainties exist in the quantification of the tonnage of waste burned. The emission factors themselves also contain large uncertainties. For a given year, for a given state, emissions for open burning have been estimated by state agencies or other groups and are included in the national emission inventory. These estimates have been used in recent air quality modeling exercises, including the EAC modeling exercise for the State of South Carolina. The open burning emissions are gross estimates only, reflecting what may have occurred in a given county/state during a particular ozone season and the quantity and quality of the waste tonnage data needed to estimate the emissions. The uncertainty in magnitude and spatial distribution of these emissions is much larger than the uncertainties associated with point sources, for example, which are often estimated using direct measurement methods.

Given the uncertainties in the open burning emissions themselves, due to the factors discussed above, however, it is reasonable to assume that 100 percent effectiveness is well within the range of uncertainty compared to say, an assumption of 80 percent effectiveness. Also, given the relatively small magnitude of these emissions, it is unlikely that the increase in emissions due to an assumption of 80 percent effectiveness will have any effects on the simulated attainment results within the various EAC areas in South Carolina compared to a 100 percent effectiveness assumption.

Point Source Emissions

Facility-Specific Emission Data

2007 Inventory

- Emissions from electric utilities are based on control levels required by the NO_x SIP call and estimated electric generation demand for the 2007 time frame.
- Southern Company provided hourly emission estimates for 2007 reflecting expected future load and operating conditions on days meteorologically similar to those occurring in the May 1998 episode.
- TVA provided emissions estimates for 2007.
- SC DHEC provided 2007 emissions estimates for SCE&G, Santee Cooper, Duke Power and CP&L facilities in South Carolina. Emissions for Santee Cooper include the proposed additional units at the Cross Generating Station but do not include the reductions to occur at Cross and Winyah Generating Stations due to the consent decree signed in 2004.
- SC DHEC provided 2007 emissions estimates for Transcontinental Pipeline, Guardian Industries and merchant power plants in South Carolina.
- 2007 emissions estimates for Celanese Acetate LLC, Rock Hill site were provided by SC DHEC.

- 2007 emissions estimates for CP&L and Duke Power facilities in North Carolina were provided by SC DHEC. The CP&L 2007 estimates were provided by the State of North Carolina via SC DHEC. These estimates were originally made for a 19 June – 1 July 1996 episode for a North Carolina modeling project. The emission data were used for the May 1998 episode, matched by day of the week. In addition to NO_x SIP call requirements, emissions from North Carolina utilities are also reduced based on the requirements of North Carolina's Clean Smokestacks regulation.

2012 Inventory

- Emissions from electric utilities are based on control levels required by the NO_x SIP call and estimated electric generation demand for the 2012 time frame.
- Southern Company provided hourly emission estimates for 2012 reflecting expected future load and operating conditions on days meteorologically similar to those occurring in the May 1998 episode.
- TVA provided emissions estimates for 2010, and used for 2012 inventory.
- SC DHEC provided 2012 emissions estimates for SCE&G, Santee Cooper and CP&L facilities in South Carolina. Emissions for Santee Cooper include the proposed additional units at the Cross Generating Station but do not include the reductions to occur at Cross and Winyah Generating Stations due to the consent decree signed in 2004.
- Revised 2010 emissions estimates for Duke Power facilities in North Carolina and South Carolina were provided by SC DHEC, and recommended by Duke that the 2010 estimates to be used for 2012 inventory.
- SC DHEC provided 2012 emissions estimates for Transcontinental Pipelines, Guardian Industries and merchant plants in South Carolina.
- 2012 emissions estimates for Celanese Acetate LLC, Rock Hill site were provided by SC DHEC.
- 2012 emissions for CP&L facilities in North Carolina were provided by SC DHEC (the same emissions data were used for the 2010 baseline inventory).

2017 Inventory

- Emissions for utilities in South Carolina and North Carolina were kept at the 2012 emissions level. These emissions do not include any reductions expected from the proposed interstate air quality rule.
- Emissions from merchant power plants were kept at their 2012 emissions level. These emissions do not include any reductions expected from the proposed interstate air quality rule.
- Emissions estimates for Transcontinental Pipeline, Guardian Industries, and Celanese Acetate, LLC were projected to 2017 from their 2012 levels.

Point Source Growth

The future-year growth estimates for all other point sources located in the domain were based on BEA GSP projections. The BEA projections were applied at the 2-digit Standard Industrial Classification (SIC) level for point sources, and represent growth between the base year and future year (2007, 2012, and 2017).

Point Source Controls

For fuel combustion sources, energy adjustment factors, which were developed from DOE publication "Annual Energy Outlook 1999," were applied to the baseline emissions to account for increases in fuel and process efficiency in 2007, 2012, and 2017.

The CAA controls include federal initiatives that were applied to the non-utility point sources, as shown in Table 7-5. In addition, MACT controls for NO_x and VOC were applied to the non-utilities. The MACT control assumptions are listed in Tables 7-6 and 7-7.

NO_x SIP Call Control

The emission controls required by the EPA's Regional NO_x SIP Call were emulated for the point sources located in the modeling domain covered by the SIP Call, i.e., the States of Alabama, Georgia, Illinois, Indiana, Kentucky, Maryland, Missouri, North Carolina, South Carolina, Tennessee, Virginia, and West Virginia. The NO_x SIP Call controls were applied to the point sources located north of the 32-degree latitude line in the states of Alabama and Georgia.

The Electric Generation Unit (EGU) and non-EGU point sources subject to the NO_x SIP Call in the point source inventory needed to be identified in order to apply NO_x emission controls. EPA's "Development of Emission Budget Inventories for Regional Transport NO_x SIP Call Technical Amendment Version" (EPA, 1999b) provided lists of EGU and non-EGU point sources, and the data were utilized to identify the EGU and non-EGU sources in the point source inventory.

Electric Generating Units (EGUs)

The point sources included in the inventory were matched with the EGUs included in the EPA's Emission Budget Inventory for Regional Transport NO_x SIP Call. The FIPS, plant ID, and point ID provided in the EGU data file were used to complete the match. Where point IDs are not consistent in both inventories, EGUs in the point source inventory were identified by the FIPS and plant ID. In the end, a small portion of the EGU units in the EPA's data file could not be found in the point source inventory by FIPS, plant ID, or point ID matches. Some of these sources may be located outside the modeling domain, in the states which are only partially included in the domain. Due to the inconsistencies of the inventories, more time and effort would be needed to complete the match. However, the major NO_x emitters listed in the EPA's EGU data file were successfully identified in the point source inventory, in particular, the major NO_x emitters located in Alabama, Georgia, and Tennessee.

The NO_x control factors for the EGUs were calculated using the 1996 NO_x emission rates (lb/MMBtu) provided in the EPA's EGU data file for each source, and a uniform emission rate of 0.15 lb/MMBtu for the year of 2007, 2012, and 2017.

Non-Electric Generating Units (EGUs)

The point sources included in the inventory were matched with the large-size non-EGUs included in the EPA's Emission Budget Inventory for Regional Transport NO_x SIP Call. The FIPS, plant ID, point ID, and SCC provided in the non-EGU data file were used to complete the match. Where point IDs are not consistent in both inventories, non-EGUs in the point source inventory were identified by FIPS, plant ID, and SCC. In the end, a small portion of the non-EGU sources in the EPA's data file could not be found in the point source inventory by the FIPS, plant ID, point ID, or SCC matches. Some of these sources may be located outside the modeling domain, in the states which are only partially included in the domain. Due to the inconsistencies of the inventories, more time and effort would be needed to complete the match.

The NO_x emission reductions were calculated for the large-size non-EGU sources in the source categories listed in Table 7-8, as specified by EPA (1999b).

Non-road Mobile Source Emissions

County-level emission estimates for the majority of non-road mobile source emissions were developed using EPA's draft NONROAD2002 model (distributed for a limited, confidential, and secure review to selected stakeholders in November, 2002) with May maximum, minimum, and average temperatures by state as provided in EPA's "National Air Pollutant Emission Trends, Procedures Document for 1990-1996."

Emissions of aircraft, commercial marine vessels, and locomotives were projected from 1996 levels to future year (2007, 2012, and 2017) levels using the BEA GSP growth factors.

On-road Mobile Source Emissions

The on-road mobile source emissions were prepared using MOBILE6. Future year emissions estimates from MOBILE6 include benefits from Tier II low sulfur fuels. The following data were provided by the States of Alabama, Georgia, South Carolina, North Carolina, and Tennessee, and used for 2007, 2012, and 2017 mobile source emission estimates:

State of Alabama	2007, 2012, and 2017 county-level daily VMT data
State of South Carolina	MOBILE6 input for 2007, 2012, and 2017 2007, 2012, and 2017 county-level daily VMT data
State of North Carolina	MOBILE6 input for 2007, 2012, and 2017 2007, 2012, and 2017 county-level daily VMT data
State of Georgia	MOBILE6 input for 2007, 2012, and 2017 2007, 2012, and 2017 county-level daily VMT data
State of Tennessee	MOBILE6 input for 2007, 2012, and 2017 2007, 2012, and 2017 county-level daily VMT data

For the other states, the on-road mobile source emissions were prepared using MOBILE6 and state-level 2007/2012/2017 VMT data provided by FHWA. The state-level VMT data were distributed to the county-level using the 2000 Census population as a surrogate.

The MOBILE6 input files were used to generate the emission factors for total organic gases (TOG), NO_x, and CO. The county-level emissions were calculated for each vehicle class and roadway classification by multiplying the appropriate emission factor from MOBILE6 by the county-level VMT for that vehicle class and roadway classification, using the EPS 2.5 program MVCALC. The MOBILE6 input files are available as a separate attachment.

Summary of the Modeling Emissions Inventories

Summaries of the 2007, 2012, and 2017 baseline emissions for the May 1998 episode are presented in Tables 7-9 through 7-17 for each grid. The emission summaries are given by species (NO_x, VOC, and CO) and by major source category. The low-level emissions include anthropogenic sources (area, non-road, on-road motor vehicle, and low-level point sources) and biogenic sources. The units are in tons per day.

Figure 7-9 presents average daily (18 – 22 May) NO_x and VOC emissions from area sources, elevated and low-level point sources, and on-road and off-road mobile sources for the early action compact areas that have been designated non-attainment for ozone. This figure includes the 1998 data for comparison with 2007, 2012, and 2017 emissions estimates. Tables 7-18 through 7-22 contain the same information in addition to CO emissions from the above sources. Biogenic emissions are also included in these tables.

C. Future-Year Boundary Conditions Preparation

Ozone boundary conditions for the future-year simulation differ from those for the base-case simulation because they are iteratively refined using model output according to the "self-generating" boundary condition estimation technique described in Section V. Table 7-1 lists the boundary ozone values used in the final future-year simulation. In general, these are slightly lower than the base-case boundary ozone values, which can be found in Table 5-1.

Table 7-1.
Ozone concentrations used as boundary conditions for the future-year simulation, as calculated using the self-generating ozone boundary condition technique.

Date	Boundary Ozone (ppb)
5/16/98	60
5/17/98	57.95
5/18/98	60.79
5/19/98	62.65
5/20/98	64.83
5/21/98	65.35
5/22/98	63.74
5/23/98	62.76

D. Future-Year Baseline Simulation

Note that the baseline simulation was refined on several occasions during the course of the future year modeling exercise. The results presented here represent the final future-year baseline simulation.

As outlined in the previous subsections the 2007, 2012, and 2017 future-year baseline simulations incorporate the effects of population and industry growth, technology changes, and national or statewide control measures that are expected to be in place by 2007, 2012, or 2017, depending on the simulation. For the South Carolina subdomain (Grid 3), projection of emissions to 2007 result in approximate decreases of 38% and 17%, respectively, of anthropogenic NO_x and VOC, and about a 3% reduction in total VOC. Projection of emissions to 2012 result in approximate decreases of 38% and 18%, respectively, of anthropogenic NO_x and VOC, and about a 3% reduction in total VOC, as compared to the 1998 base case. For 2017, projection of emissions result in approximate decreases of 39% and 19%, respectively, of anthropogenic NO_x and VOC, and about a 3% reduction in total VOC, as compared to the 1998 base case.

While only the emissions inputs were directly modified for the future year simulations, the “self-generating” boundary condition inputs changed slightly as a result; this is also described in the previous subsection. The future-year ozone values used for the boundary conditions are typically 1 to 2 ppb lower than the base-case values, depending on the simulation day.

Figure 7-1 plots the maximum simulated 8-hour ozone concentrations for the future-year simulation for Grid 3 for each simulation day for the 2007 run. Figure 7-2 plots the maximum simulated 8-hour ozone concentrations for the future-year simulation for Grid 3 for each simulation day for the 2012 run. Figure 7-3 plots the maximum simulated 8-hour ozone concentrations for the future-year simulation for Grid 3 for each simulation day for the 2017 run.

Figure 7-4 shows contour plots of cell-by-cell differences in maximum 8-hour ozone concentration between the 2007 and 1998 simulations for Grid 3 for each simulation day. The domain-wide maximum and minimum differences are provided on the upper right-hand corner of each plot. For the South Carolina subdomain in the 2007 run, the predominant negative contours on these plots indicate reductions of four to eight ppb in most areas, with some areas experiencing reductions of up to twelve ppb. For the 2007 run, positive contours are confined to only a few small areas; excluding the two start-up days, these disbenefits range from zero to four ppb. Overall, the 2007 future-year simulation shows more and greater decreases than increases in peak 8-hour ozone relative to the base case simulation.

Figure 7-5 shows contour plots of cell-by-cell differences in maximum 8-hour ozone concentration between the 2012 and 1998 simulations for Grid 3 for each simulation day. For the South Carolina subdomain in the 2012 run, the predominant negative contours on these plots indicate reductions of eight to twelve ppb in most areas, with some areas experiencing reductions of over twelve ppb. For the 2012 run, positive contours are confined to only a few small areas; excluding the two start-up days, these disbenefits range from zero to two ppb. Overall, the 2012 future-year simulation shows more and greater decreases than increases in peak 8-hour ozone relative to the base case simulation.

Figure 7-6 shows contour plots of cell-by-cell differences in maximum 8-hour ozone concentration between the 2017 and 1998 simulations for Grid 3 for each simulation day. For the South Carolina subdomain in the 2017 run, the predominant negative contours on these plots indicate reductions of eight to twelve ppb in most areas, with some areas experiencing reductions of over twelve ppb. For the 2017 run, positive contours are confined to only a few small areas; excluding the two start-up days, these disbenefits range from zero to two ppb. Overall, the 2017 future-year simulation shows more and greater decreases than increases in peak 8-hour ozone relative to the base case simulation.

Eight-hour ozone exceedance exposures for the simulations are compared in Figure 7-7, for the South Carolina subdomain (Grid 3), the State of South Carolina, and the four key areas of interest within the state. This is a measure of the “excess” simulated 8-hour concentration that is greater than 85 ppb, in units of ppb. This measure is summed for all days excluding the two start-up days. The value is zero in the Florence/Darlington area and the Rock Hill area because no sites in these areas had simulated future-year concentrations greater than 85 ppb in 2007, 2012, or 2017. The Columbia area also achieves a zero value in 2017. For the other areas, the large differences represent lower 8-hour concentrations, over smaller spatial areas, over shorter intervals of time.

Figure 7-8 displays the area-wide maximum simulated 8-hour ozone concentrations for the three simulations, for the same areas as in Figure 7-7. As in the above calculations, these maximums do not consider the two start-up days. All areas show absolute reductions from 1998 peak simulated ozone concentrations ranging from 9 to 13 ppb for 2007, from 10 to 24 ppb for 2012, and from 11 to 26 ppb for

2017. The future year simulated values are still greater than 85 ppb for three of the five areas of interest in 2007 and 2012; in 2017 only two areas still exceed 85 ppb. However, the EPA's draft 8-hour attainment demonstration procedures consider relative differences between future- and base-year simulations, rather than absolute future-year results. Relative reductions are examined in the following section that covers an 8-hour attainment demonstration.

Table 7-2.
Area Source VOC Control Measure Assumptions

Control Measure	Affected ASCs	VOC Percentage Reduction	VOC Rule Effectiveness
Federal Control Measures (National)			
Consumer Solvents	2465000000	25	100
Consumer Solvents	2465100000	25	100
Consumer Solvents	2465200000	25	100
Consumer Solvents	2465400000	25	100
Consumer Solvents	2465600000	25	100
Consumer Solvents	2465800000	25	100
Architectural Coatings	2401001000	25	100
Architectural Coatings	2401001999	25	100
Industrial Maintenance Coatings	2401100000	25	100
Traffic Markings	2401008000	25	100
Title III MACT (National)			
Wood Furniture Surface Coating	2401020000	30	100
Aerospace Surface Coating	2401075000	60	100
Marin Vessel Surface Coating (Shipbuilding)	2401080000	24	100
Halogenated Solvent Cleaners (Cold Cleaning)	2415300000	43	100
Halogenated Solvent Cleaners (Cold Cleaning)	2415305000	43	100
Halogenated Solvent Cleaners (Cold Cleaning)	2415310000	43	100
Halogenated Solvent Cleaners (Cold Cleaning)	2415320000	43	100
Halogenated Solvent Cleaners (Cold Cleaning)	2415325000	43	100
Halogenated Solvent Cleaners (Cold Cleaning)	2415330000	43	100
Halogenated Solvent Cleaners (Cold Cleaning)	2415335000	43	100
Halogenated Solvent Cleaners (Cold Cleaning)	2415340000	43	100
Halogenated Solvent Cleaners (Cold Cleaning)	2415345000	43	100
Halogenated Solvent Cleaners (Cold Cleaning)	2415355000	43	100
Halogenated Solvent Cleaners (Cold Cleaning)	2415360000	43	100
Autobody Refinishing	2401005000	37	100
Petroleum Refinery Fugitives	2306000000	60	100
Synthetic Organic Chemical Manufacturing Industry (SOCMI), Fugitives	2301040000	37	100
Motor Vehicle Surface Coating	2401070000	36	100
Metal Product Surface Coating	2401040000	36	100
Metal Product Surface Coating	2401045000	36	100
Metal Product Surface Coating	2401050000	36	100
Wood Product Surface Coating	2401015000	36	100
Open Top & Converyorized Degreasing	2415000000	31	100

Control Measure	Affected ASCs	VOC Percentage Reduction	VOC Rule Effectiveness
Open Top & Converyorized Degreasing	2415105000	31	100
Open Top & Converyorized Degreasing	2415110000	31	100
Open Top & Converyorized Degreasing	2415120000	31	100
Open Top & Converyorized Degreasing	2415125000	31	100
Open Top & Converyorized Degreasing	2415130000	31	100
Open Top & Converyorized Degreasing	2415135000	31	100
Open Top & Converyorized Degreasing	2415140000	31	100
Open Top & Converyorized Degreasing	2415145000	31	100
Open Top & Converyorized Degreasing	2415199000	31	100
Open Top & Converyorized Degreasing	2415200000	31	100
Public Owned Treatment Works (POTWs)	2630000000	80	100
Public Owned Treatment Works (POTWs)	2630020000	80	100
Metal Furniture & Appliances Surface Coating	2401025000	36	100
Metal Furniture & Appliances Surface Coating	2401060000	36	100
Machinery, Railroad Surface Coating	2401550000	36	100
Machinery, Railroad Surface Coating	2401085000	36	100
Machinery, Railroad Surface Coating	2401090000	36	100
Electronic Coating	2401065000	36	100
Title I RACT			
Petroleum Dry Cleaning	2420000370	44	80
Petroleum Dry Cleaning	2420010370	44	80
Paper Surface Coating	2401030000	78	80

Table 7-3.
Residential Wood Combustion Control Efficiency

Pollutant	Percent Reduction
VOC	49
CO	37

Table 7-4.
Vehicle Refueling VOC Control Efficiency

Does County Have Stage II Controls?	Percent Reduction
No	52.0
Yes	81.7

Table 7-5.
Point Source CAA Baseline VOC Control Assumptions

Source Category	Control Efficiency (%)
National Rules	
Marine vessel loading: petroleum liquids	80
Treatment, storage, and disposal facilities (TSDFs)	96
Municipal solid waste landfills	82

Table 7-6.
Point Source MACT Control Assumptions

Source Category	VOC Control Efficiency (%)*
Benzene National Emission Standards for Hazardous Air Pollutants (NESHAP) (national)	
By-product coke mfg	85
By-product coke - flushing-liquor circulation tank	95
By-product cokeexcess-NH_3 liquor tank	98
By-product coke mfg. - tar storage	98
By-product coke mfg. - light oil sump	98
By-product coke mfg. - light oil dec/cond vents	98
By-product coke mfg. - tar bottom final cooler	81
By-product coke mfg. - naphthalene processing	100
By-product coke mfg. - equipment leaks	83
By-product coke manufactureother	94
By-product coke manufacture - oven charging	94
Coke ovens - door and topside leaks	94
Coke oven by-product plants	94
2-Year MACT (national)	
Synthetic Organic Chemical Manufacturing Industry (SOCMI) Hazardous Organic NESHAP (HON)	
– SOCMI processes	79
– Volatile organic liquid storage	95
– SOCMI fugitives (equipment leak detection and repair)	60
– SOCMI wastewater	0
– Ethylene oxide manufacture	98
– Phenol manufacture	98
– Acrylonitrile manufacture	98
– Polypropylene manufacture	98

Source Category	VOC Control Efficiency (%)*
– Polyethylene manufacture	98
– Ethylene manufacture	98
Dry Cleaning	
– Perchloroethylene	95
– Other	70
4-Year MACT (national)	
TSDFs (offsite waste operations)	96
Shipbuilding and repair	24
Polymers and resins II	78
Polymers and resins IV	70
Styrene-butadiene rubber manufacture (polymers & resins group I)	70
Wood furniture surface coating	30
Aircraft surface coating (aerospace)	60
Petroleum Refineries: other sources	
– Fixed roof petroleum product tanks	98
– Fixed roof gasoline tanks	96
– External floating roof petroleum product tanks	90
– External floating roof gasoline tanks	95
– Petroleum refinery wastewater treatment	72
– Petroleum refinery fugitives	72
– Petroleum refineries - Blowdown w/o control	78
– Vacuum distillation	72
Halogenated Solvent Cleaners	
– Open top degreasinghalogenated	63
– In-line (conveyorized) degreasinghalogenated	39
Printing	
– Flexographic	32
– Gravure	27
Gasoline Marketing	
– Storage	5
– Splash loading	99
– Balanced loading	87
– Submerged loading	99
– Transit	5

Source Category	VOC Control Efficiency (%)*
– Leaks	39
7/10-Year MACT (national)	
Paint and varnish manufacture	35
Rubber tire manufacture	70
Green tire spray	90
Automobile surface coating	79
Beverage can surface coating	57
Paper surface coating	78
Flatwood surface coating	90
Fabric printing	80
Metal surface coating	90
Plastic parts surface coating	45
Pulp and paper production	70
Agricultural chemical production	79
Pharmaceutical production	79
Polyesters	70
Fabric coating	70
Petroleum refineries - fluid catalytic cracking	70
Oil and natural gas production	90
Explosives	70
Plywood/particle board	70
Reinforced plastics	70
Publicly-Owned Treatment Works (POTWs)	70
Phthalate plasticizers	70
Polymers and resins III	78
Rayon production	70
Polyvinyl chloride	70
Spandex production	70
Nylon 6 production	70
Alkyd resins	70
Polyester resins	70
Chelating agents	70

*NOTE: *From uncontrolled levels.*

Table 7-7.
Non-VOC-Related MACT Assumptions

Source Category	Pollutant	Percentage Reduction (%)*
Medical Waste Incineration	NOx	20

*NOTE: *From uncontrolled levels.*

Table 7-8.
NO_x Reduction Levels from Uncontrolled Emissions for Non-EGU Sources

Source Category	Budget Reduction Percentage
Percentage	
ICI Boilers*- Coal/Wall	60
ICI Boilers - Coal/FBC	60
ICI Boilers - Coal/Stoker	60
ICI Boilers - Coal/Cyclone	60
ICI Boilers - Residual Oil	60
ICI Boilers - Distillate Oil	60
ICI Boilers - Natural Gas	60
ICI Boilers - Process Gas	60
ICI Boilers – LPG	60
ICI Boilers – Coke	60
Gas Turbines – Oil	60
Gas Turbines - Natural Gas	60
Gas Turbines - Jet Fuel	60
Internal Combustion Engines – Oil	90
Internal Combustion Engines – Gas	90
Internal Combustion Engines - Gas, Diesel, LPG	90
Cement Manufacturing – Dry	30
Cement Manufacturing – Wet	30
In-Process; Bituminous Coal; Cement Kiln	30

* *Industrial/Commercial/Institutional Boilers*

Table 7-9.
Summary of 2007 Baseline Emissions for May 1998 Episode (tons/day) in Grid 1

NOx	070516	070517	070518	070519	070520	070521	070522	070523
Area	1114	151	1154	1154	1154	1154	1154	1114
Motor vehicle	3314	2900	3487	3556	3521	3590	3832	3314
Non-road	2621	2621	3046	3046	3046	3046	3046	2621
Low-level point	311	306	333	333	333	333	333	311
Biogenic	943	927	919	968	971	991	877	859
All low-level	8303	6905	8939	9057	9025	9114	9242	8219
Elevated point	5708	5620	5918	5952	5938	5952	5928	5708
TOTAL	**14010**	**12524**	**14857**	**15008**	**14964**	**15067**	**15170**	**13927**

VOC	070516	070517	070518	070519	070520	070521	070522	070523
Area	3845	2976	6846	6846	6846	6846	6846	3845
Motor vehicle	2255	1973	2373	2420	2396	2443	2608	2255
Non-road	2064	2064	1283	1283	1283	1283	1283	2064
Low-level point	704	638	1119	1119	1119	1119	1119	704
Biogenic	73762	73669	76814	85866	77747	81801	50713	44857
All low-level	82629	81320	88435	97534	89392	93493	62569	53725
Elevated point	515	492	581	582	582	583	582	515
TOTAL	**83144**	**81812**	**89016**	**98116**	**89974**	**94076**	**63152**	**54239**

CO	070516	070517	070518	070519	070520	070521	070522	070523
Area	4443	3503	5208	5208	5208	5208	5208	4443
Motor vehicle	22006	19255	23152	23610	23381	23839	25444	22006
Non-road	18291	18291	17600	17600	17600	17600	17600	18291
Low-level point	707	699	724	724	724	724	724	707
Biogenic	0	0	0	0	0	0	0	0
All low-level	45446	41748	46683	47142	46913	47371	48976	45446
Elevated point	5108	5069	5255	5280	5280	5277	5286	5108
TOTAL	**50554**	**46816**	**51938**	**52422**	**52193**	**52648**	**54262**	**50554**

Table 7-10.
Summary of 2007 Baseline Emissions for May 1998 Episode (tons/day) in Grid 2

NOx	070516	070517	070518	070519	070520	070521	070522	070523
Area	403	79	428	428	428	428	428	403
Motor vehicle	1950	1707	2052	2093	2072	2113	2255	1950
Non-road	870	870	1092	1092	1092	1092	1092	870
Low-level point	125	122	136	136	136	136	136	125
Biogenic	395	387	376	386	401	414	377	366
All low-level	3743	3164	4084	4135	4130	4183	4289	3714
Elevated point	2032	2002	2053	2081	2089	2088	2056	2032
TOTAL	**5775**	**5165**	**6137**	**6216**	**6220**	**6271**	**6345**	**5746**

VOC	070516	070517	070518	070519	070520	070521	070522	070523
Area	2092	1563	3887	3887	3887	3887	3887	2092
Motor vehicle	1283	1122	1350	1376	1363	1390	1483	1283
Non-road	970	970	632	632	632	632	632	970
Low-level point	383	345	671	671	671	671	671	383
Biogenic	42318	37763	39449	43844	41895	46268	33792	28148
All low-level	47045	41764	45989	50410	48448	52848	40465	32875
Elevated point	151	144	181	183	183	183	183	151
TOTAL	**47196**	**41908**	**46170**	**50593**	**48631**	**53031**	**40648**	**33026**

CO	070516	070517	070518	070519	070520	070521	070522	070523
Area	2679	2172	3129	3129	3129	3129	3129	2679
Motor vehicle	13557	11862	14263	14545	14404	14686	15675	13557
Non-road	8951	8951	8862	8862	8862	8862	8862	8951
Low-level point	434	428	444	444	444	444	444	434
Biogenic	0	0	0	0	0	0	0	0
All low-level	25621	23413	26698	26980	26839	27122	28110	25621
Elevated point	1364	1351	1396	1422	1426	1419	1426	1364
TOTAL	**26986**	**24765**	**28094**	**28403**	**28265**	**28541**	**29536**	**26986**

Table 7-11.
Summary of 2007 Baseline Emissions for May 1998 Episode (tons/day) in Grid 3

NOx	070516	070517	070518	070519	070520	070521	070522	070523
Area	153	38	163	163	163	163	163	153
Motor vehicle	1007	881	1059	1080	1070	1091	1164	1007
Non-road	371	371	503	503	503	503	503	371
Low-level point	36	35	39	39	39	39	39	36
Biogenic	176	174	169	170	177	189	170	164
All low-level	1743	1499	1933	1956	1952	1985	2039	1731
Elevated point	775	757	874	882	887	907	881	775
TOTAL	**2518**	**2256**	**2807**	**2837**	**2839**	**2892**	**2920**	**2506**

VOC	070516	070517	070518	070519	070520	070521	070522	070523
Area	1099	817	2094	2094	2094	2094	2094	1099
Motor vehicle	722	632	759	774	767	782	835	722
Non-road	409	409	306	306	306	306	306	409
Low-level point	142	123	319	319	319	319	319	142
Biogenic	21777	18505	19885	21567	18982	24258	17438	13491
All low-level	24150	20486	23364	25061	22468	27759	20992	15864
Elevated point	64	62	87	88	88	88	88	64
TOTAL	**24213**	**20548**	**23451**	**25149**	**22556**	**27847**	**21080**	**15927**

CO	070516	070517	070518	070519	070520	070521	070522	070523
Area	1313	1078	1528	1528	1528	1528	1528	1313
Motor vehicle	7605	6654	8001	8160	8080	8239	8793	7605
Non-road	4657	4657	5085	5085	5085	5085	5085	4657
Low-level point	70	69	75	75	75	75	75	70
Biogenic	0	0	0	0	0	0	0	0
All low-level	13645	12458	14689	14848	14768	14927	15481	13645
Elevated point	593	590	646	670	669	664	672	593
TOTAL	**14238**	**13048**	**15335**	**15517**	**15437**	**15591**	**16154**	**14238**

Table 7-12.
Summary of 2012 Baseline Emissions for May 1998 Episode (tons/day) in Grid 1

NOx	120516	120517	120518	120519	120520	120521	120522	120523
Area	1138	153	1181	1181	1181	1181	1181	1138
Motor vehicle	2169	1898	2282	2328	2305	2350	2508	2169
Non-road	2715	2715	3084	3084	3084	3084	3084	2715
Low-level point	326	321	349	349	349	349	349	326
Biogenic	943	927	919	968	971	991	877	859
All low-level	7291	6014	7816	7909	7890	7955	8000	7208
Elevated point	5989	5963	6188	6165	6170	6196	6181	5989
TOTAL	**13280**	**11977**	**14004**	**14074**	**14060**	**14152**	**14181**	**13197**

VOC	120516	120517	120518	120519	120520	120521	120522	120523
Area	4066	3138	7302	7302	7302	7302	7302	4066
Motor vehicle	1651	1445	1737	1771	1754	1789	1909	1651
Non-road	1877	1877	1234	1234	1234	1234	1234	1877
Low-level point	751	681	1198	1198	1198	1198	1198	751
Biogenic	73762	73669	76814	85866	77747	81801	50713	44857
All low-level	82107	80810	88285	97372	89236	93325	62356	53202
Elevated point	543	519	612	614	614	615	615	543
TOTAL	**82649**	**81329**	**88898**	**97986**	**89850**	**93939**	**62971**	**53745**

CO	120516	120517	120518	120519	120520	120521	120522	120523
Area	4494	3518	5292	5292	5292	5292	5292	4494
Motor vehicle	18909	16546	19894	20288	20091	20485	21864	18909
Non-road	19739	19739	19199	19199	19199	19199	19199	19739
Low-level point	745	737	763	763	763	763	763	745
Biogenic	0	0	0	0	0	0	0	0
All low-level	43887	40540	45149	45543	45346	45740	47118	43887
Elevated point	5429	5389	5563	5594	5594	5591	5599	5429
TOTAL	**49316**	**45929**	**50712**	**51137**	**50939**	**51331**	**52717**	**49316**

Table 7-13.
Summary of 2012 Baseline Emissions for May 1998 Episode (tons/day) in Grid 2

NOx	120516	120517	120518	120519	120520	120521	120522	120523
Area	413	80	441	441	441	441	441	413
Motor vehicle	1277	1118	1344	1370	1357	1384	1477	1277
Non-road	905	905	1103	1103	1103	1103	1103	905
Low-level point	132	128	143	143	143	143	143	132
Biogenic	395	387	376	386	401	414	377	366
All low-level	3122	2617	3406	3443	3445	3484	3541	3093
Elevated point	2126	2130	2115	2105	2107	2119	2116	2126
TOTAL	**5248**	**4747**	**5521**	**5549**	**5552**	**5603**	**5657**	**5219**

VOC	120516	120517	120518	120519	120520	120521	120522	120523
Area	2210	1645	4152	4152	4152	4152	4152	2210
Motor vehicle	966	845	1016	1036	1026	1046	1117	966
Non-road	894	894	612	612	612	612	612	894
Low-level point	410	370	720	720	720	720	720	410
Biogenic	42318	37763	39449	43844	41895	46268	33792	28148
All low-level	46798	41518	45950	50365	48405	52799	40393	32629
Elevated point	161	154	192	193	194	194	194	161
TOTAL	**46959**	**41672**	**46141**	**50558**	**48599**	**52993**	**40587**	**32789**

CO	120516	120517	120518	120519	120520	120521	120522	120523
Area	2716	2187	3187	3187	3187	3187	3187	2716
Motor vehicle	11865	10382	12483	12730	12606	12853	13719	11865
Non-road	9685	9685	9670	9670	9670	9670	9670	9685
Low-level point	458	451	469	469	469	469	469	458
Biogenic	0	0	0	0	0	0	0	0
All low-level	24723	22704	25809	26056	25932	26179	27045	24723
Elevated point	1464	1458	1476	1506	1509	1502	1512	1464
TOTAL	**26187**	**24162**	**27285**	**27562**	**27442**	**27682**	**28557**	**26187**

Table 7-14.
Summary of 2012 Baseline Emissions for May 1998 Episode (tons/day) in Grid 3

NOx	120516	120517	120518	120519	120520	120521	120522	120523
Area	157	39	169	169	169	169	169	157
Motor vehicle	677	592	712	726	719	733	782	677
Non-road	379	379	500	500	500	500	500	379
Low-level point	37	36	41	41	41	41	41	37
Biogenic	176	174	169	170	177	189	170	164
All low-level	1427	1220	1590	1606	1606	1632	1661	1415
Elevated point	858	871	923	921	930	925	928	858
TOTAL	**2285**	**2091**	**2513**	**2527**	**2535**	**2557**	**2590**	**2273**

VOC	120516	120517	120518	120519	120520	120521	120522	120523
Area	1163	860	2241	2241	2241	2241	2241	1163
Motor vehicle	546	478	575	586	580	592	632	546
Non-road	384	384	293	293	293	293	293	384
Low-level point	153	133	344	344	344	344	344	153
Biogenic	21777	18505	19885	21567	18982	24258	17438	13491
All low-level	24024	20360	23338	25031	22441	27728	20947	15738
Elevated point	70	67	93	95	95	95	95	70
TOTAL	**24094**	**20428**	**23431**	**25126**	**22536**	**27823**	**21043**	**15807**

CO	120516	120517	120518	120519	120520	120521	120522	120523
Area	1331	1085	1557	1557	1557	1557	1557	1331
Motor vehicle	6627	5799	6972	7110	7041	7179	7663	6627
Non-road	5065	5065	5551	5551	5551	5551	5551	5065
Low-level point	75	74	79	79	79	79	79	75
Biogenic	0	0	0	0	0	0	0	0
All low-level	13098	12023	14160	14298	14229	14367	14851	13098
Elevated point	654	650	685	715	717	710	721	654
TOTAL	**13752**	**12673**	**14845**	**15013**	**14946**	**15077**	**15571**	**13752**

Table 7-15.
Summary of 2017 Baseline Emissions for May 1998 Episode (tons/day) in Grid 1

NOx	170516	170517	170518	170519	170520	170521	170522	170523
Area	1169	154	1216	1216	1216	1216	1216	1169
Motor vehicle	1483	1298	1560	1591	1576	1607	1715	1483
Non-road	2839	2839	3187	3187	3187	3187	3187	2839
Low-level point	341	336	365	365	365	365	365	341
Biogenic	943	927	919	968	971	991	877	859
All low-level	6776	5554	7248	7327	7315	7365	7360	6692
Elevated point	6178	6091	6339	6300	6321	6314	6335	6178
TOTAL	**12954**	**11645**	**13586**	**13626**	**13636**	**13679**	**13694**	**12870**

VOC	170516	170517	170518	170519	170520	170521	170522	170523
Area	4106	3124	7557	7557	7557	7557	7557	4106
Motor vehicle	1444	1264	1519	1549	1534	1564	1670	1444
Non-road	1859	1859	1285	1285	1285	1285	1285	1859
Low-level point	798	723	1273	1273	1273	1273	1273	798
Biogenic	73762	73669	76814	85866	77747	81801	50713	44857
All low-level	81969	80638	88448	97530	89397	93481	62498	53064
Elevated point	575	551	649	651	652	652	652	575
TOTAL	**82544**	**81190**	**89097**	**98181**	**90049**	**94133**	**63150**	**53639**

CO	170516	170517	170518	170519	170520	170521	170522	170523
Area	4484	3469	5317	5317	5317	5317	5317	4484
Motor vehicle	17989	15741	18926	19301	19114	19488	20800	17989
Non-road	21150	21150	20809	20809	20809	20809	20809	21150
Low-level point	782	774	801	801	801	801	801	782
Biogenic	0	0	0	0	0	0	0	0
All low-level	44406	41134	45854	46228	46041	46416	47728	44406
Elevated point	5764	5727	5907	5941	5949	5941	5951	5764
TOTAL	**50169**	**46861**	**51761**	**52170**	**51990**	**52357**	**53679**	**50169**

Table 7-16.
Summary of 2017 Baseline Emissions for May 1998 Episode (tons/day) in Grid 2

NOx	170516	170517	170518	170519	170520	170521	170522	170523
Area	426	81	455	455	455	455	455	426
Motor vehicle	889	778	936	954	945	964	1028	889
Non-road	956	956	1147	1147	1147	1147	1147	956
Low-level point	138	134	151	151	151	151	151	138
Biogenic	395	387	376	386	401	414	377	366
All low-level	2804	2336	3064	3093	3099	3130	3158	2775
Elevated point	2119	2093	2096	2073	2084	2098	2101	2119
TOTAL	**4924**	**4429**	**5159**	**5166**	**5183**	**5228**	**5260**	**4895**

VOC	170516	170517	170518	170519	170520	170521	170522	170523
Area	2234	1634	4311	4311	4311	4311	4311	2234
Motor vehicle	894	783	941	960	950	969	1034	894
Non-road	897	897	640	640	640	640	640	897
Low-level point	437	395	768	768	768	768	768	437
Biogenic	42318	37763	39449	43844	41895	46268	33792	28148
All low-level	46780	41471	46109	50523	48564	52956	40545	32610
Elevated point	174	168	207	210	211	212	211	174
TOTAL	**46954**	**41638**	**46316**	**50733**	**48775**	**53168**	**40757**	**32784**

CO	170516	170517	170518	170519	170520	170521	170522	170523
Area	2706	2154	3199	3199	3199	3199	3199	2706
Motor vehicle	11442	10012	12038	12276	12157	12396	13230	11442
Non-road	10418	10418	10486	10486	10486	10486	10486	10418
Low-level point	482	475	493	493	493	493	493	482
Biogenic	0	0	0	0	0	0	0	0
All low-level	25048	23058	26216	26454	26335	26574	27408	25048
Elevated point	1578	1571	1592	1629	1636	1634	1641	1578
TOTAL	**26626**	**24629**	**27808**	**28083**	**27971**	**28208**	**29049**	**26626**

Table 7-17.
Summary of 2017 Baseline Emissions for May 1998 Episode (tons/day) in Grid 3

NOx	170516	170517	170518	170519	170520	170521	170522	170523
Area	162	39	174	174	174	174	174	162
Motor vehicle	481	421	506	516	511	522	557	481
Non-road	399	399	517	517	517	517	517	399
Low-level point	39	38	43	43	43	43	43	39
Biogenic	176	174	169	170	177	189	170	164
All low-level	1258	1071	1409	1421	1423	1445	1460	1246
Elevated point	846	831	895	875	886	899	898	846
TOTAL	**2104**	**1902**	**2304**	**2296**	**2308**	**2343**	**2358**	**2092**

VOC	170516	170517	170518	170519	170520	170521	170522	170523
Area	1168	846	2325	2325	2325	2325	2325	1168
Motor vehicle	532	465	560	571	565	576	615	532
Non-road	395	395	307	307	307	307	307	395
Low-level point	164	143	367	367	367	367	367	164
Biogenic	21777	18505	19885	21567	18982	24258	17438	13491
All low-level	24036	20354	23444	25137	22546	27833	21052	15750
Elevated point	75	73	100	103	104	104	104	75
TOTAL	**24111**	**20427**	**23544**	**25240**	**22650**	**27937**	**21156**	**15825**

CO	170516	170517	170518	170519	170520	170521	170522	170523
Area	1317	1059	1554	1554	1554	1554	1554	1317
Motor vehicle	6419	5616	6753	6887	6820	6953	7421	6419
Non-road	5495	5495	6028	6028	6028	6028	6028	5495
Low-level point	79	78	84	84	84	84	84	79
Biogenic	0	0	0	0	0	0	0	0
All low-level	13310	12249	14419	14552	14485	14619	15087	13310
Elevated point	700	701	737	775	778	774	784	700
TOTAL	**14010**	**12950**	**15156**	**15327**	**15264**	**15394**	**15871**	**14010**

Table 7-18.
Anderson Greenville Spartanburg Area Episode Emissions

Anderson Greenville Spartanburg Area	1998 (tpd)			2007 (tpd)			2012 (tpd)			2017 (tpd)		
	NO_x	VOC	CO	NO_x	VOC	CO	NO_x	VOC	CO	NO_x	VOC	CO
Area	13.3	185.4	70.3	13.7	174.6	59.4	14.2	188.3	61.0	14.7	190.4	56.9
Elevated point	58.5	2.1	4.8	48.2	2.7	20.7	57.9	2.9	21.1	58.7	3.1	21.5
Motor vehicles	84.5	69.9	719.8	38.0	50.3	495.4	28.7	39.9	439.0	22.7	35.4	424.8
Non-road mobile	36.4	24.9	275.4	25.2	16.4	324.9	24.6	15.4	353.2	25.2	15.7	381.8
Low-level point	4.2	20.4	2.5	4.6	16.9	2.7	4.8	18.5	2.8	5.0	20.0	3.0
Biogenic	5.0	639.2	0	5.0	639.2	0	5.0	639.2	0	5.0	639.2	0

Table 7-19.
Anderson Area Episode Emissions

Anderson Area	1998 (tpd)			2007 (tpd)			2012 (tpd)			2017 (tpd)		
	NO_x	VOC	CO	NO_x	VOC	CO	NO_x	VOC	CO	NO_x	VOC	CO
Area	3.1	43.2	20.0	3.2	39.7	16.8	3.3	42.7	17.2	3.4	42.7	16.0
Elevated point	18.2	0.5	0.2	15.9	0.7	6.5	17.1	0.8	6.5	17.2	0.8	6.5
Motor vehicles	19.1	15.8	164.4	8.6	11.4	113.2	6.6	9.2	101.8	5.4	8.3	100.3
Non-road mobile	6.9	4.3	43.9	4.7	2.7	42.8	4.6	2.5	46.1	4.7	2.4	49.5
Low-level point	1.0	3.2	0.6	1.1	2.6	0.6	1.1	2.8	0.6	1.1	3.0	0.6
Biogenic	1.5	158.7	0	1.5	158.7	0	1.5	158.7	0	1.5	158.7	0

Table 7-20.
Greenville Area Episode Emissions

Greenville Area	1998 (tpd)			2007 (tpd)			2012 (tpd)			2017 (tpd)		
	NO_x	VOC	CO	NO_x	VOC	CO	NO_x	VOC	CO	NO_x	VOC	CO
Area	5.3	72.8	24.2	5.5	68.7	20.9	5.7	74.2	21.4	5.9	75.4	20.2
Elevated point	17.8	0.3	2.9	14.5	0.3	8.5	14.5	0.4	8.9	14.6	0.4	9.2
Motor vehicles	33.8	28.7	285.1	15.0	20.3	194.1	11.2	15.9	170.7	8.6	14.0	163.6
Non-road mobile	17.1	12.9	148.2	11.8	8.9	191.2	11.5	8.4	208.8	11.8	8.8	226.5
Low-level point	1.3	9.6	0.7	1.4	6.6	0.7	1.5	7.3	0.7	1.5	7.9	0.8
Biogenic	1.5	169.1	0	1.5	169.1	0	1.5	169.1	0	1.5	169.1	0

Table 7-21.
Spartanburg Area Episode Emissions

Spartanburg Area	1998 (tpd)			2007 (tpd)			2012 (tpd)			2017 (tpd)		
	NO_x	VOC	CO	NO_x	VOC	CO	NO_x	VOC	CO	NO_x	VOC	CO
Area	3.7	60.0	20.1	3.8	58.3	17.2	3.9	63.1	17.7	4.1	64.3	16.6
Elevated point	8.2	1.3	1.3	10.5	1.4	1.6	10.5	1.5	1.6	11.2	1.7	1.7
Motor vehicles	27.4	22.2	233.5	12.4	16.2	163.2	9.4	12.9	144.6	7.5	11.4	139.5
Non-road mobile	10.2	5.3	67.3	7.4	3.4	82.3	7.3	3.1	89.3	7.5	3.1	96.5
Low-level point	2.0	7.0	1.4	2.2	7.0	1.6	2.4	7.7	1.6	2.5	8.4	1.7
Biogenic	1.6	167.5	0	1.6	167.5	0	1.6	167.5	0	1.6	167.5	0

Table 7-22.
Columbia Area Episode Emissions

Columbia Area	1998 (tpd)			2007 (tpd)			2012 (tpd)			2017 (tpd)		
	NO_x	VOC	CO	NO_x	VOC	CO	NO_x	VOC	CO	NO_x	VOC	CO
Area	7.7	77.7	37.2	8.0	76.3	36.5	8.3	82.3	37.8	8.6	83.9	37.7
Elevated point	65.6	1.0	8.4	28.1	1.0	11.9	28.5	1.0	12.8	30.0	1.1	13.6
Motor vehicles	51.1	43.1	441.4	22.5	31.3	302.7	17.1	24.9	267.9	13.7	22.1	259.3
Non-road mobile	17.5	12.7	126.8	11.2	7.3	149.7	10.7	6.8	164.0	10.9	7.9	180.7
Low-level point	1.0	11.4	6.9	1.1	5.4	8.0	1.1	5.9	8.6	1.2	6.5	9.2
Biogenic	2.8	360.5	0	2.8	360.5	0	2.8	360.5	0	2.8	360.5	0

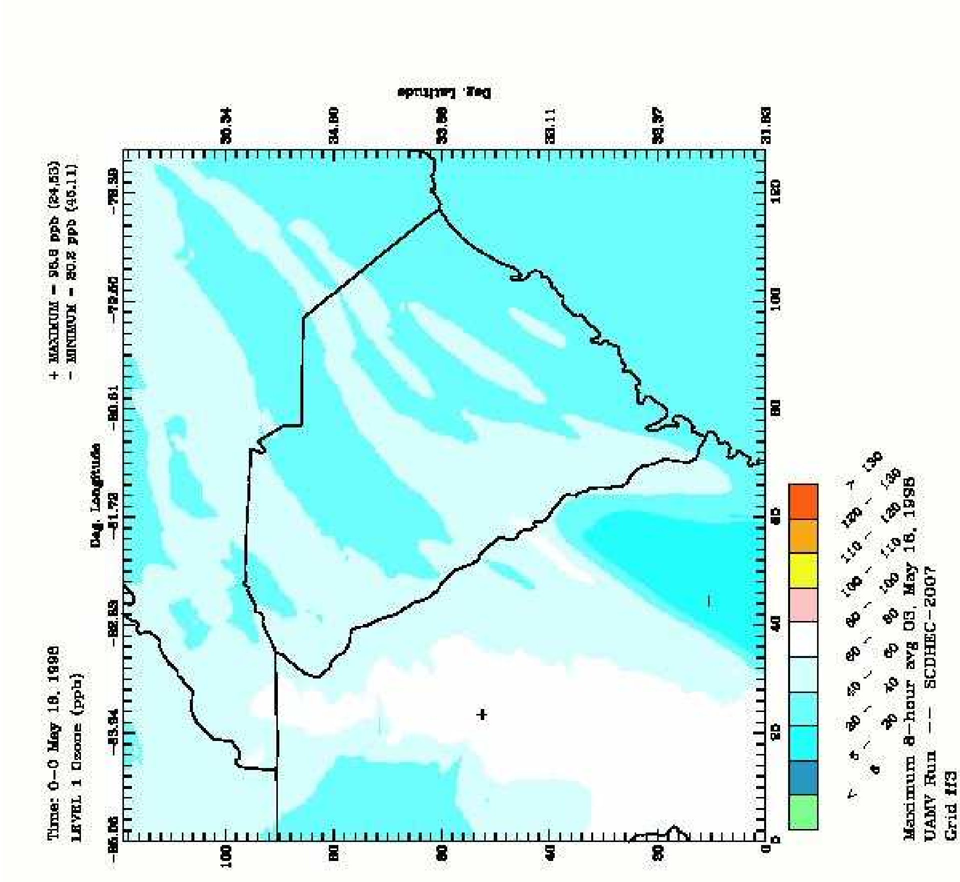
Time: 0-0 May 18, 1998
LEVEL 1 Ozone (ppb)
Deg. Longitude
Deg. Latitude
Maximum 8-hour avg O3, May 18, 1998
UAMV Run -- SCDHEC-2007
Grid #3

Figure 7-1a.

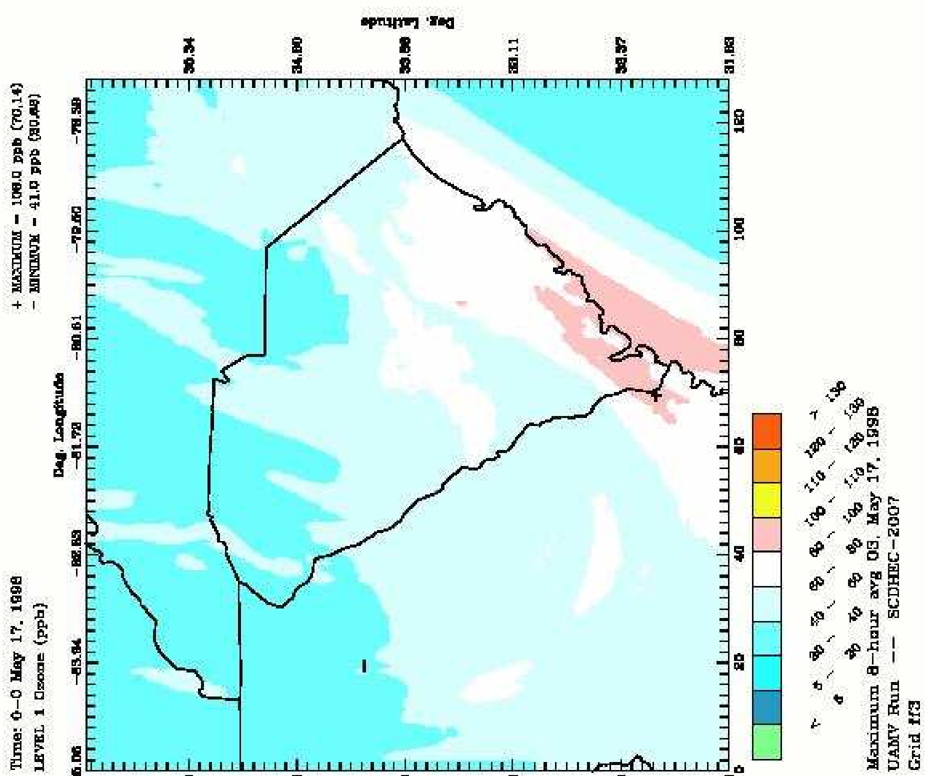
Time: 0-0 May 17, 1998
LEVEL 1 Ozone (ppb)
Deg. Longitude
Deg. Latitude
Maximum 8-hour avg O3, May 17, 1998
UAMV Run -- SCDHEC-2007
Grid ff3

Figure 7-1b.

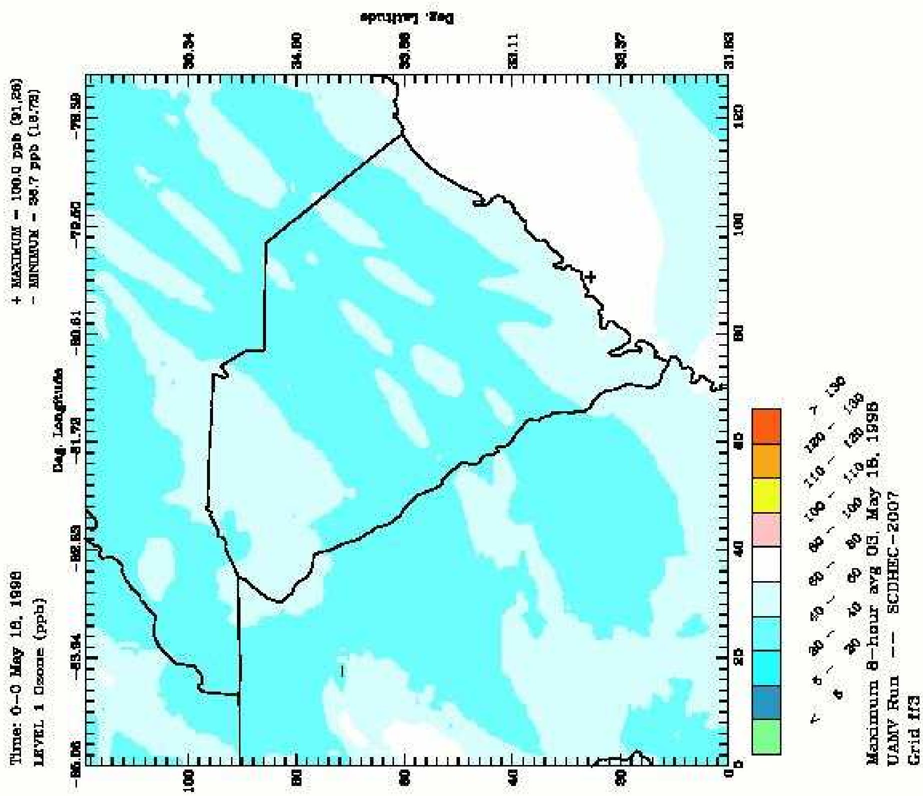
Time: 0-0 May 18, 1998
LEVEL 1 Ozone (ppb)
Deg. Longitude
Deg. Latitude
Maximum 8-hour avg 03, May 18, 1998
UAMV Run -- SCDHEC-2007
Grid #3

Figure 7-1c.

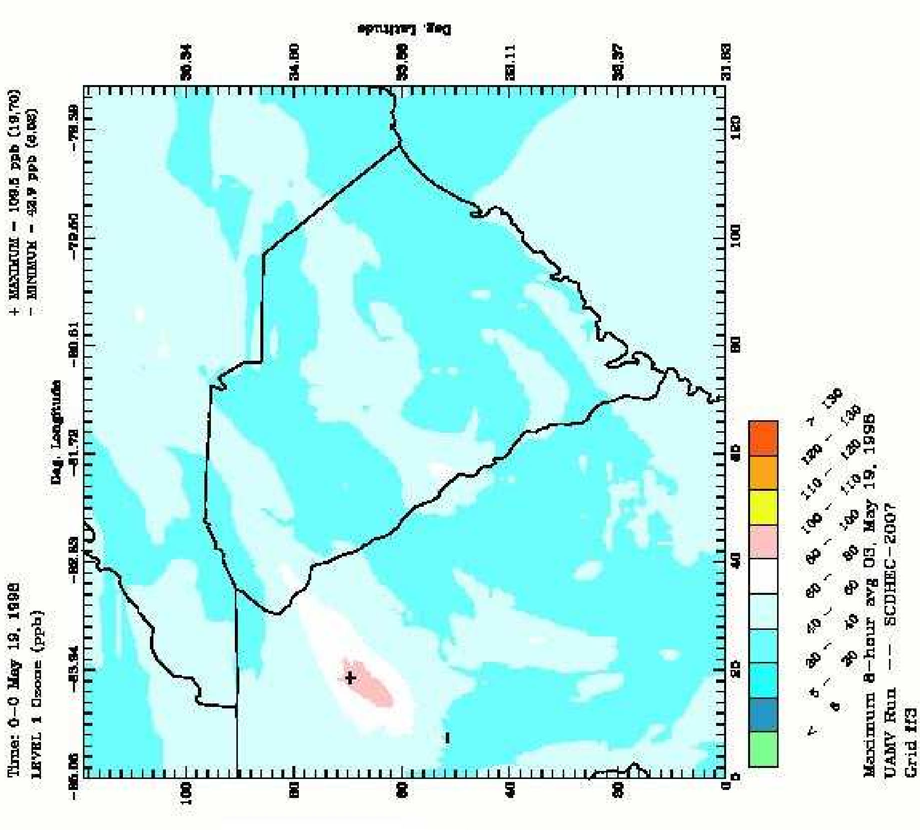
Time: 0-0 May 19, 1998
LEVEL 1 Ozone (ppb)
Deg. Longitude
Deg. Latitude
Maximum 8-hour avg O3, May 19, 1998
UAMV Run --- SCDHEC-2007
Grid #3

Figure 7-1d.

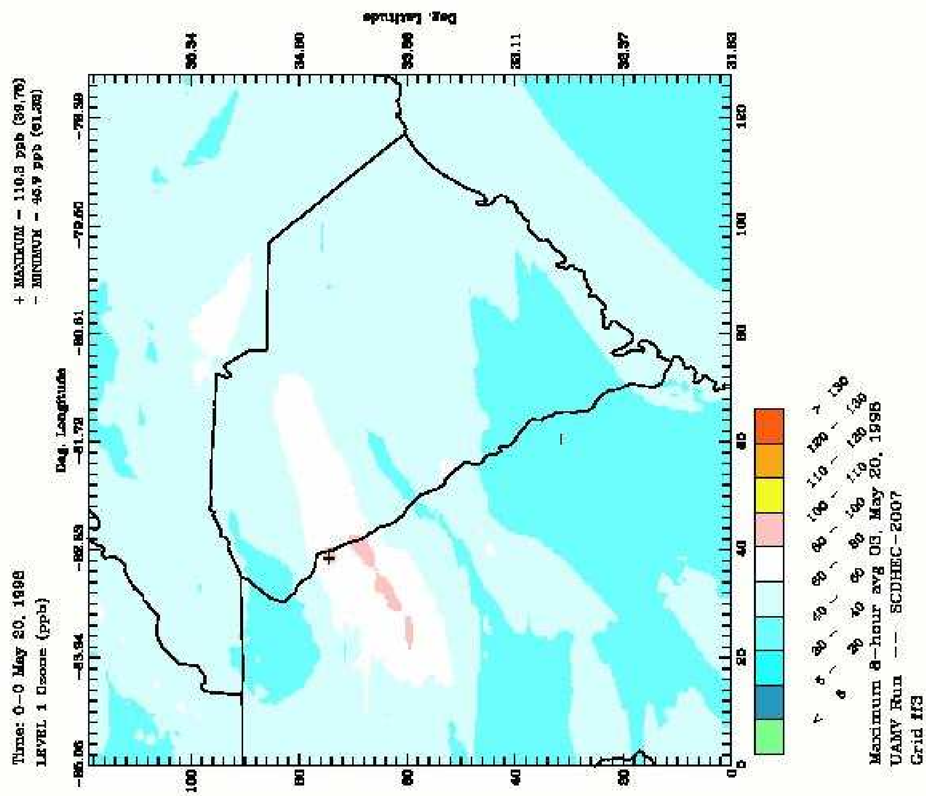
Time: 0-0 May 20, 1998
LEVEL 1 Ozone (ppb)
Deg. Longitude
Deg. Latitude
Maximum 8-hour avg O3, May 20, 1998
UAMV Run -- SCDHEC-2007
Grid #3

Figure 7-1e.

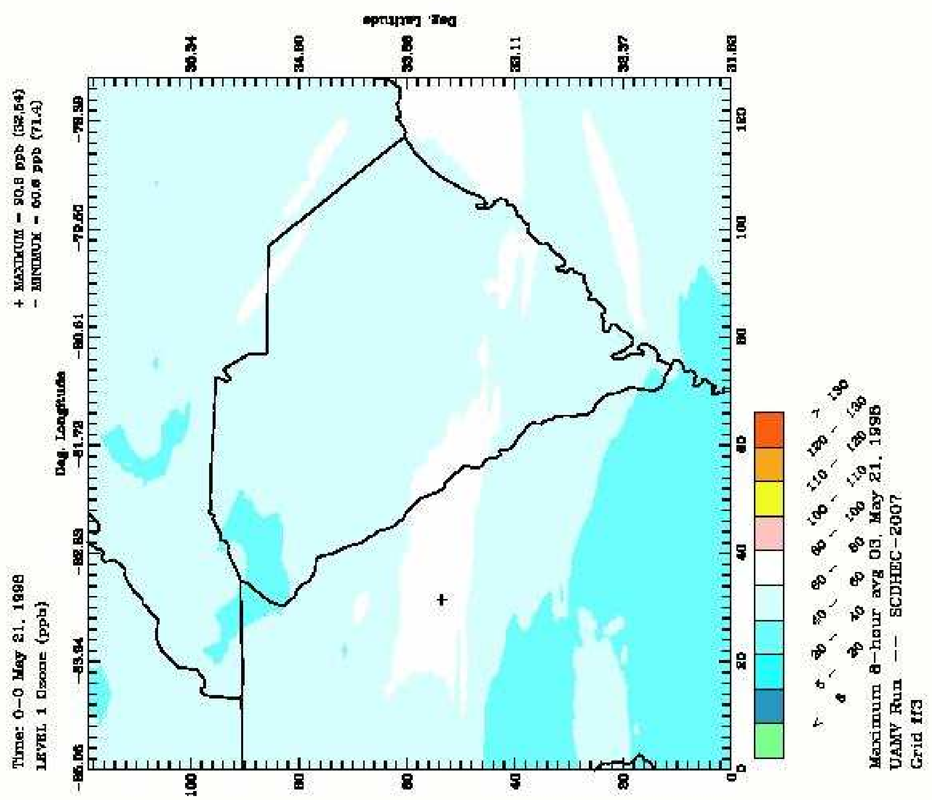
Time: 0-0 May 21, 1998
LEVEL 1 Ozone (ppb)
Deg. Longitude
Deg. Latitude
Maximum 8-hour avg 03, May 21, 1998
UAMV Run -- SCDHEC-2007
Grid #3

Figure 7-1f.

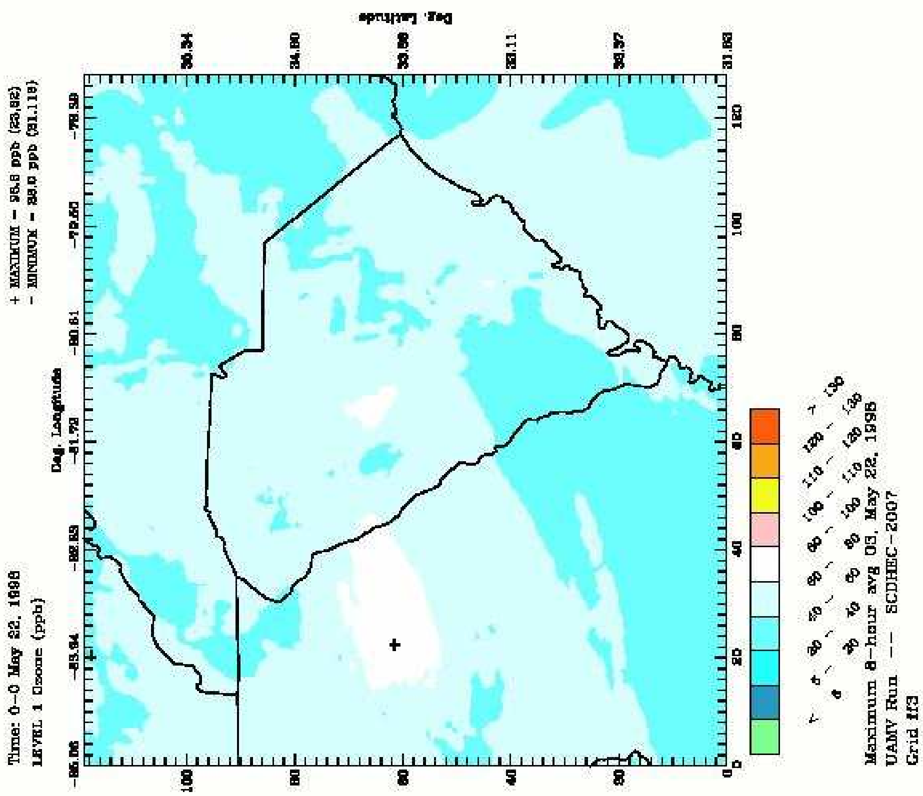
Time: 0-0 May 22, 1998
LEVEL 1 Ozone (ppb)
Deg. Longitude
Deg. Latitude
Maximum 8-hour avg 03, May 22, 1998
UAMV Run -- SCDHEC-2007
Grid #3

Figure 7-1g.

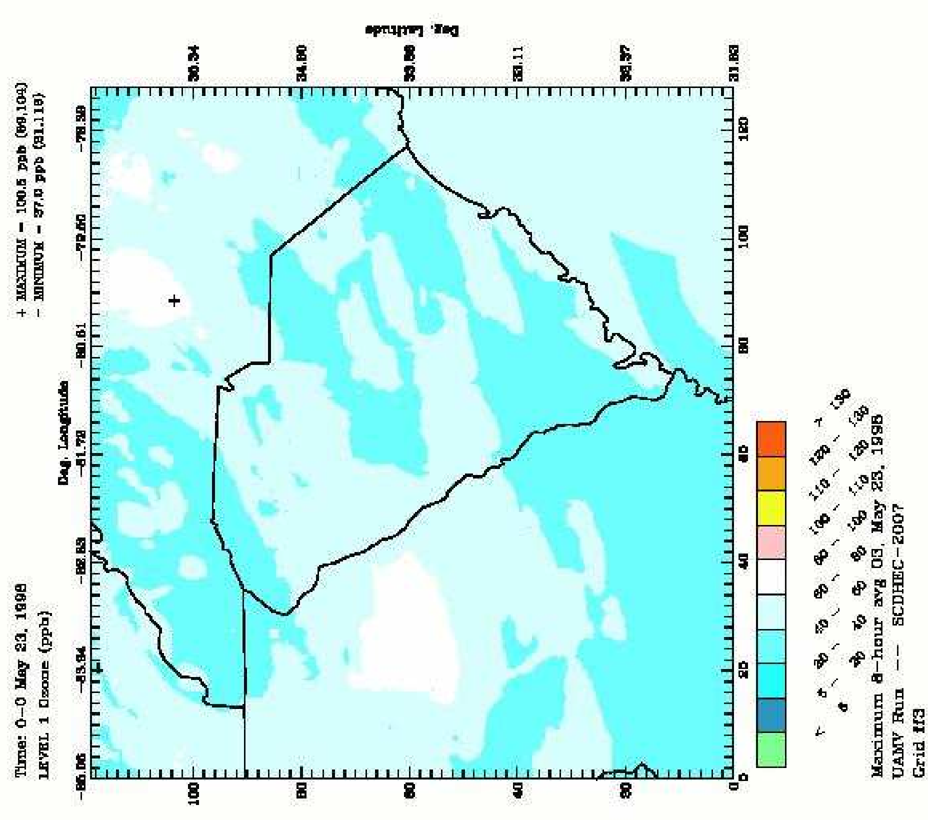
Time: 0-0 May 23, 1998
LEVEL 1 Ozone (ppb)
Deg. Longitude
Deg. Latitude
Maximum 8-hour avg 03, May 23, 1998
UAMV Run -- SCDHEC-2007
Grid #3

Figure 7-1h.

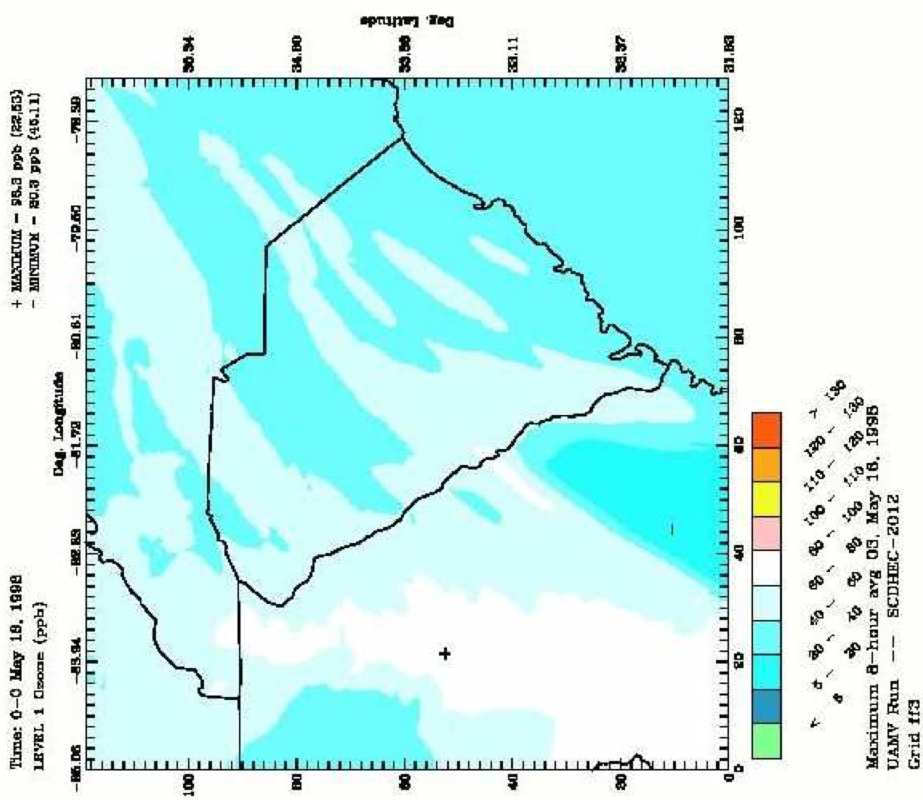
Deg. Latitude
Deg. Longitude
LEVEL 1 Ozone (ppb)
UAMV Run -- SCDHEC-2012
Grid ff3

Figure 7-2a.

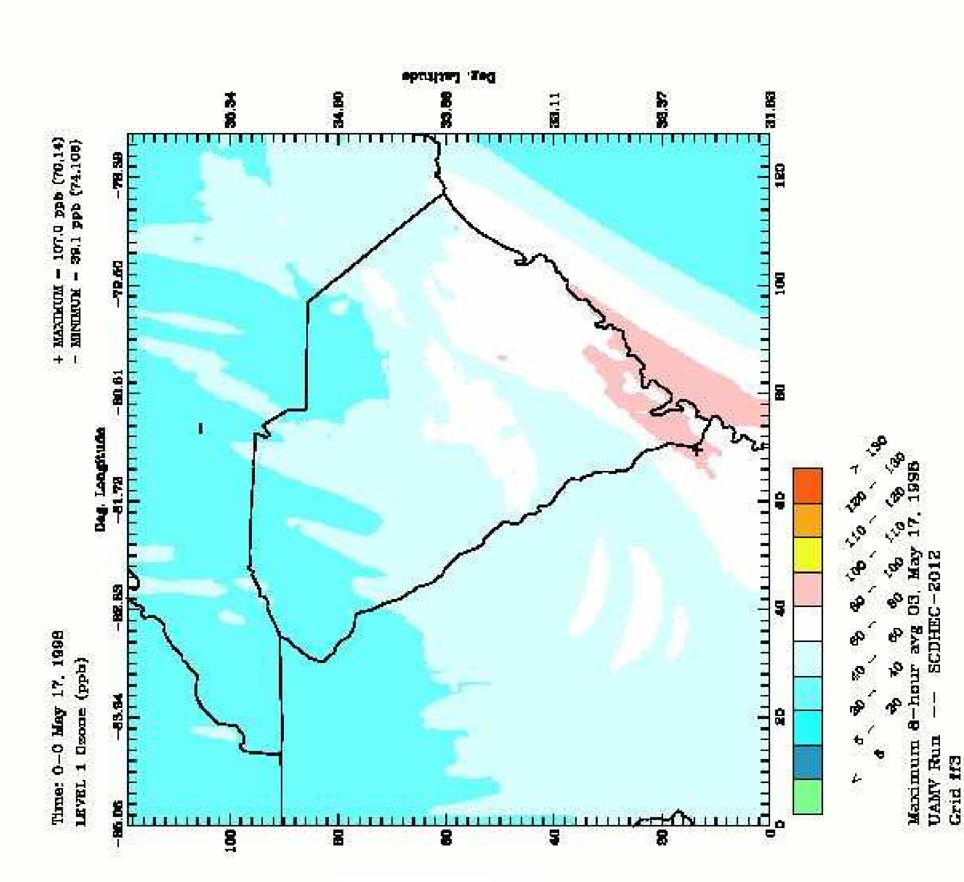
Time: 0-0 May 17, 1998
LEVEL 1 Ozone (ppb)
+ MAXIMUM = 107.0 ppb (70,14)
- MINIMUM = 39.1 ppb (74,108)
Deg. Longitude
Deg. Latitude
Maximum 8-hour avg O3, May 17, 1998
UAMV Run -- SCDHEC-2012
Grid #3

Figure 7-2b.

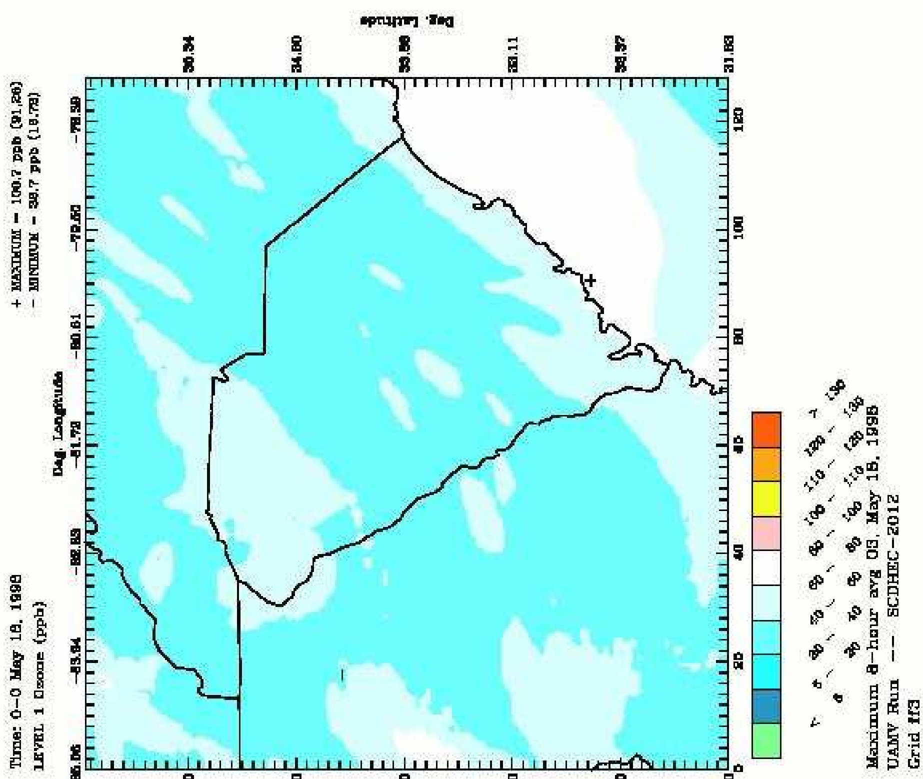
Time: 0-0 May 18, 1998
LEVEL 1 Ozone (ppb)
Deg. Longitude
Deg. Latitude
Maximum 8-hour avg O3, May 18, 1998
UAMV Run --- SCDHEC-2012
Grid #3

Figure 7-2c.

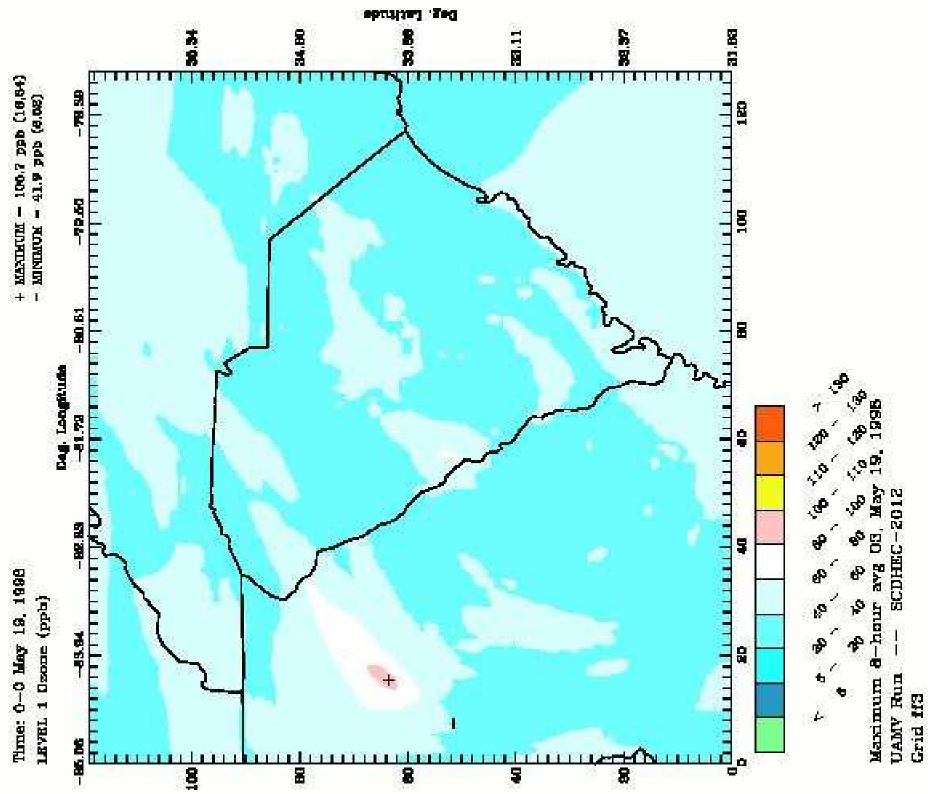
Time: 0-0 May 19, 1998
LEVEL 1 Ozone (ppb)
Deg. Longitude
Deg. Latitude
Maximum 8-hour avg 03, May 19, 1998
UAMV Run -- SCDHEC-2012
Grid #3

Figure 7-2d.

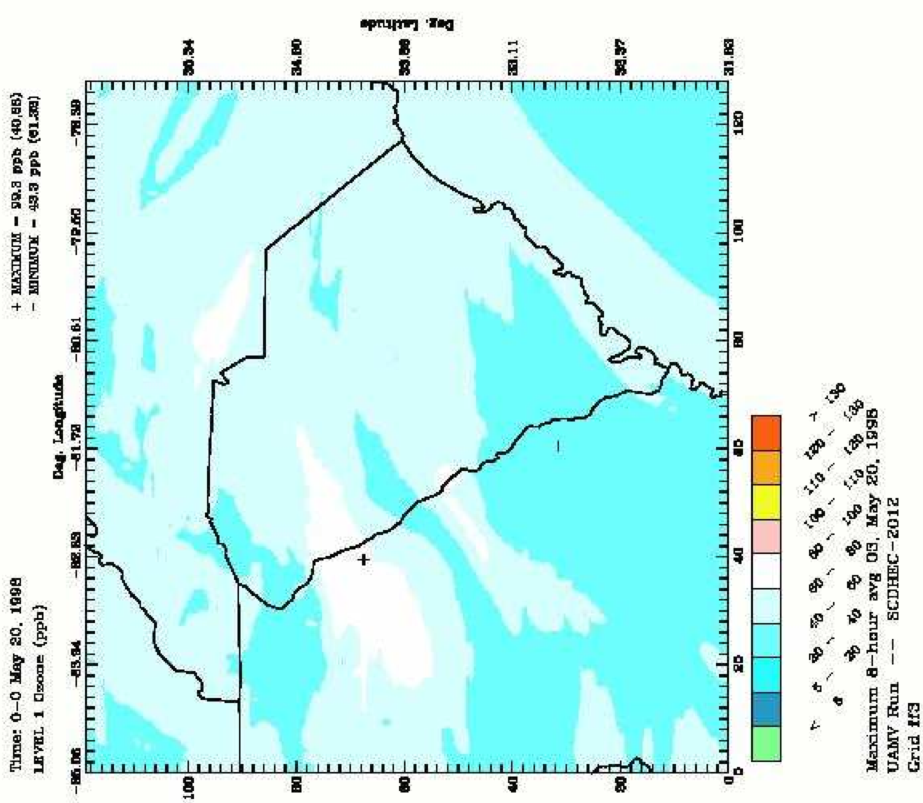
Time: 0-0 May 20, 1998
LEVEL 1 Ozone (ppb)
Deg. Longitude
Deg. Latitude
Maximum 8-hour avg O3, May 20, 1998
UAMV Run -- SCDHEC-2012
Grid #3

Figure 7-2e.

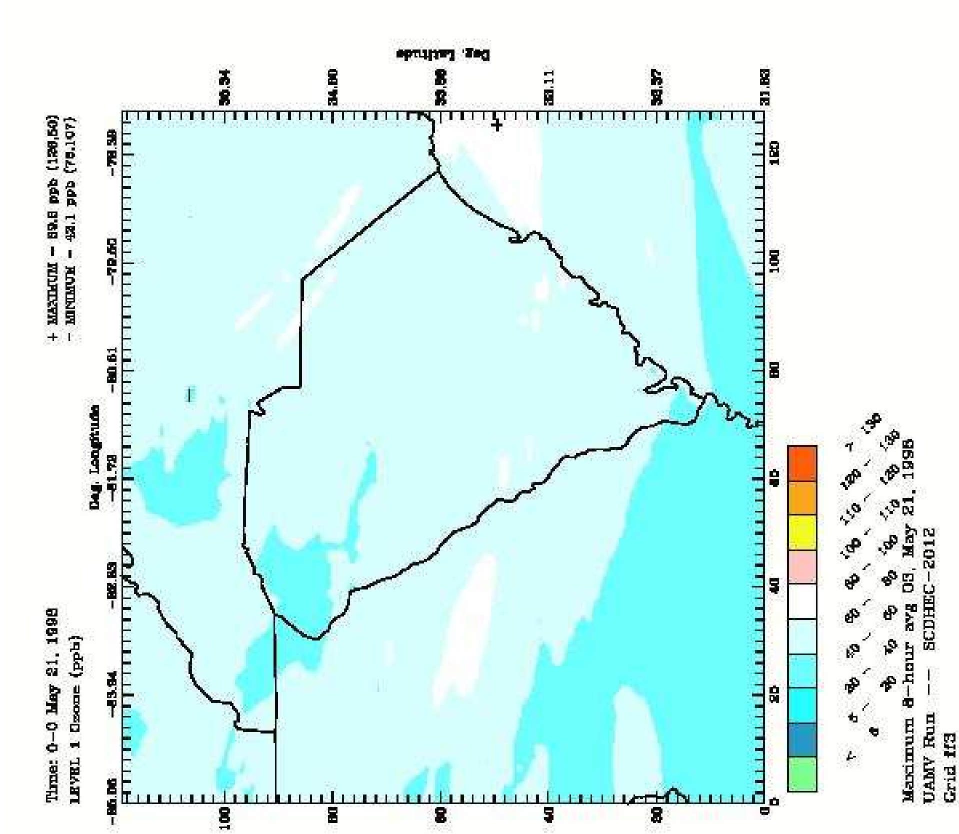
Time: 0-0 May 21, 1998
LEVEL 1 Ozone (ppb)
+ MAXIMUM = 59.8 ppb (126,50)
- MINIMUM = 23.1 ppb (75,107)
Deg. Longitude
Deg. Latitude
Maximum 8-hour avg O3, May 21, 1998
UAMV Run -- SCDHEC-2012
Grid #3

Figure 7-2f.

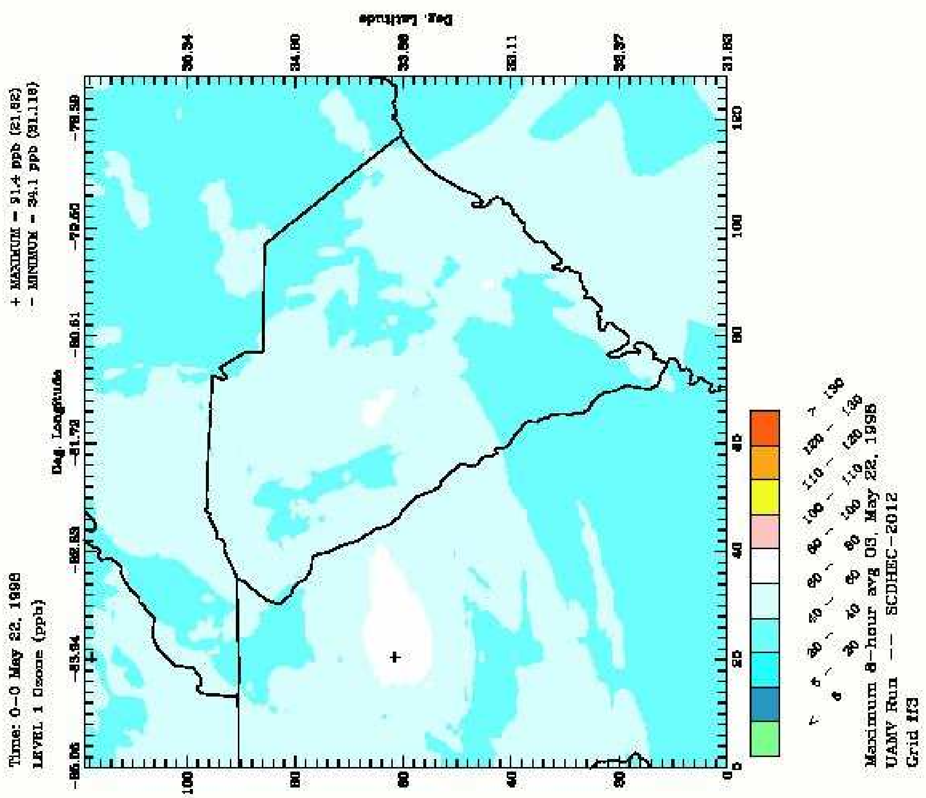
Time: 0-0 May 22, 1998
LEVEL 1 Ozone (ppb)
+ MAXIMUM = 91.4 ppb (21,92)
- MINIMUM = 34.1 ppb (91,118)
Deg. Longitude
Deg. Latitude
Maximum 8-hour avg O3, May 22, 1998
UAMV Run -- SCDHEC-2012
Grid #3

Figure 7-2g.

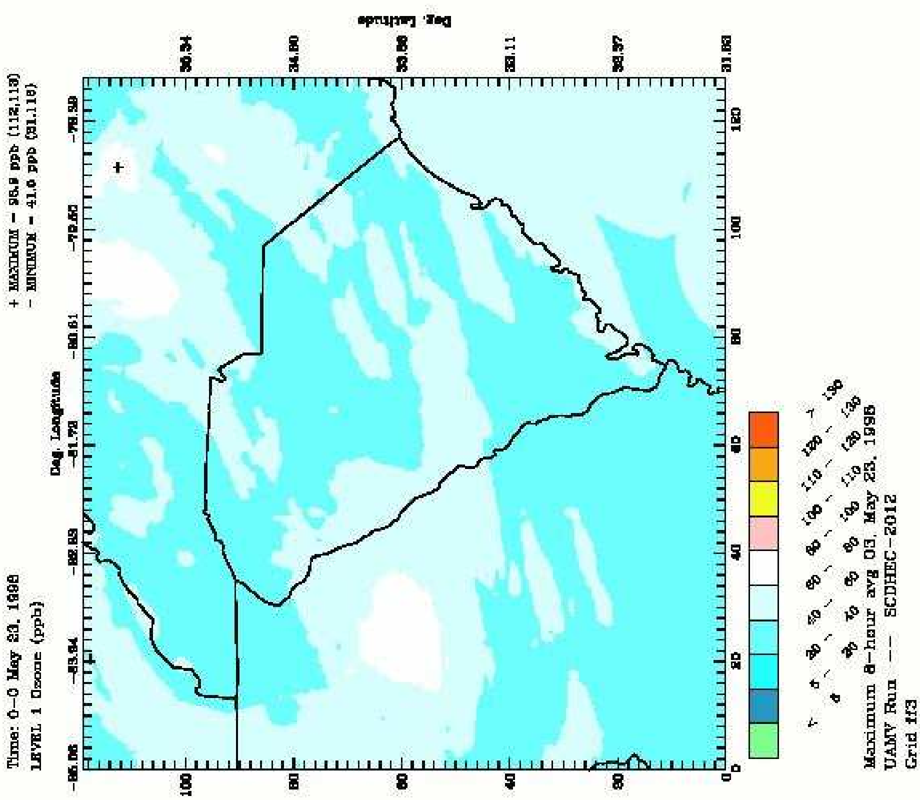
Deg. Latitude
Deg. Longitude
LEVEL 1 Ozone (ppb)
Maximum 8-hour avg 03, May 23, 1998
UAMV Run -- SCDHEC-2012
Grid ff3

Figure 7-2h.

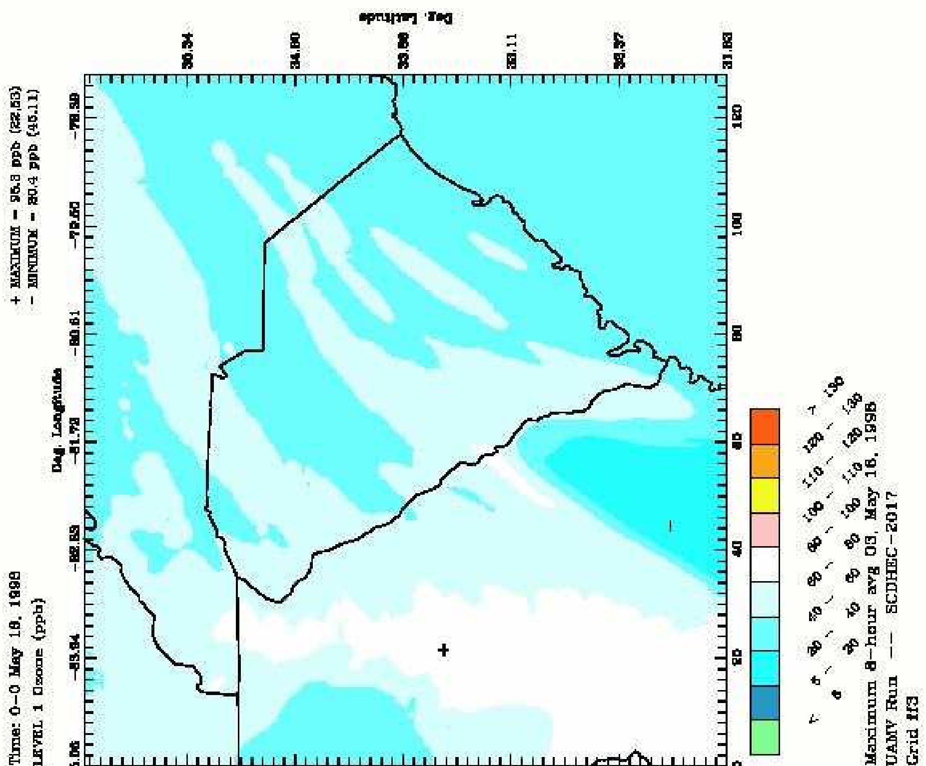

Figure 7-3a.

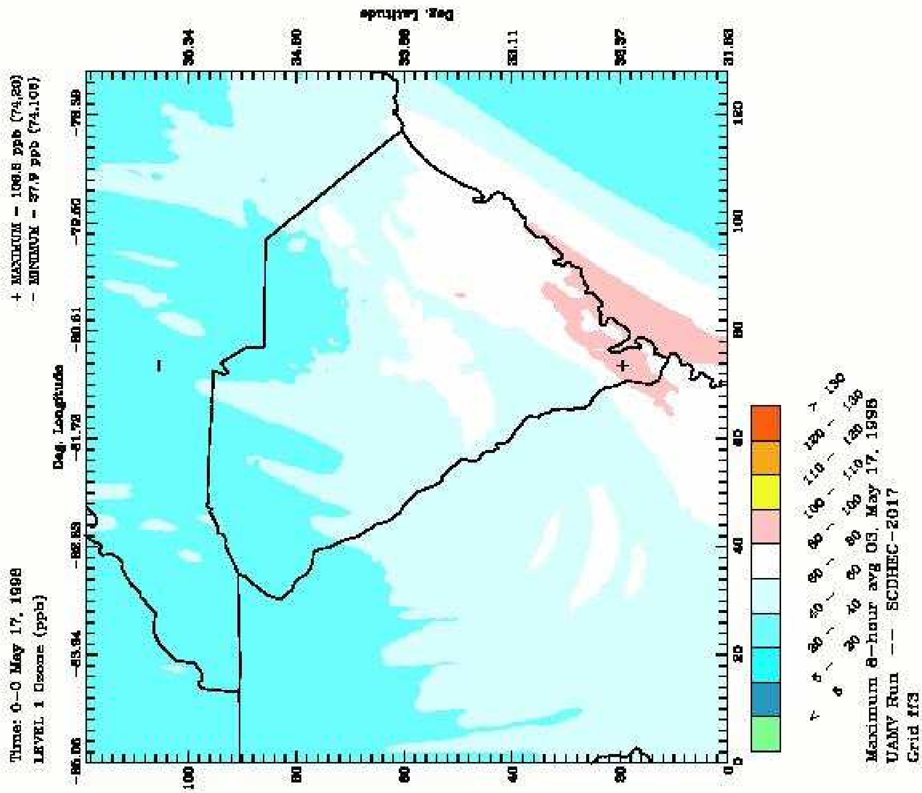
Time: 0-0 May 17, 1998
LEVEL 1 Ozone (ppb)
+ MAXIMUM = 106.8 ppb (74,20)
- MINIMUM = 37.9 ppb (74,105)
Deg. Longitude
Deg. Latitude
Maximum 8-hour avg O3, May 17, 1998
UAMV Run -- SCDHEC-2017
Grid #3

Figure 7-3b.

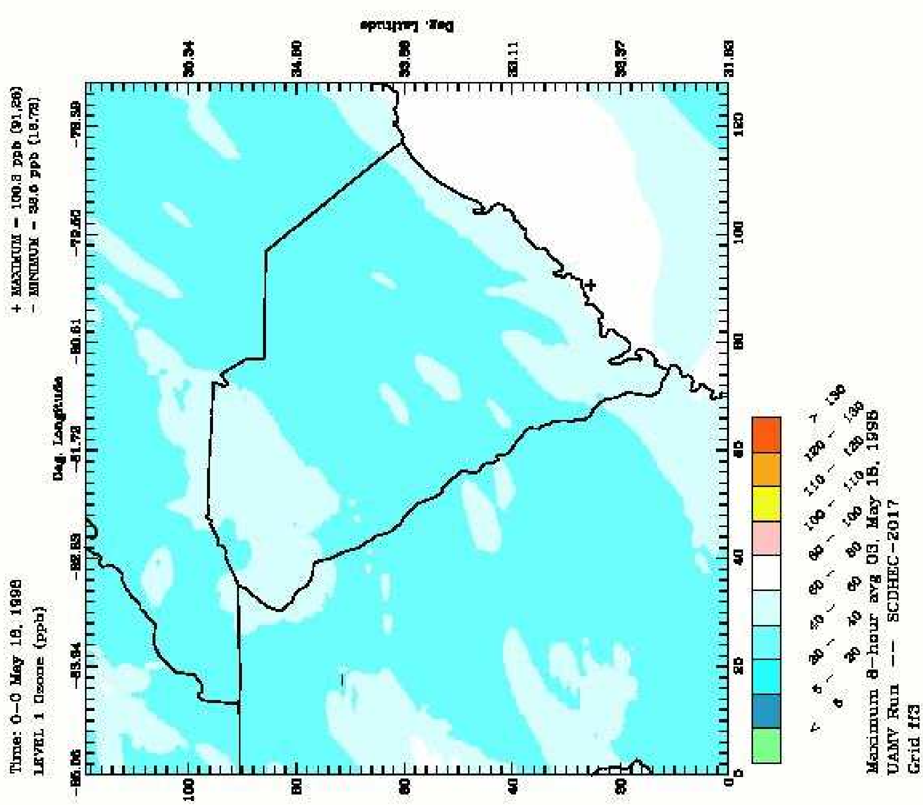
Time: 0-0 May 18, 1998
LEVEL 1 Ozone (ppb)
Deg. Longitude
Deg. Latitude
Maximum 8-hour avg 03. May 18, 1998
UAMV Run -- SCDHEC-2017

Figure 7-3c.

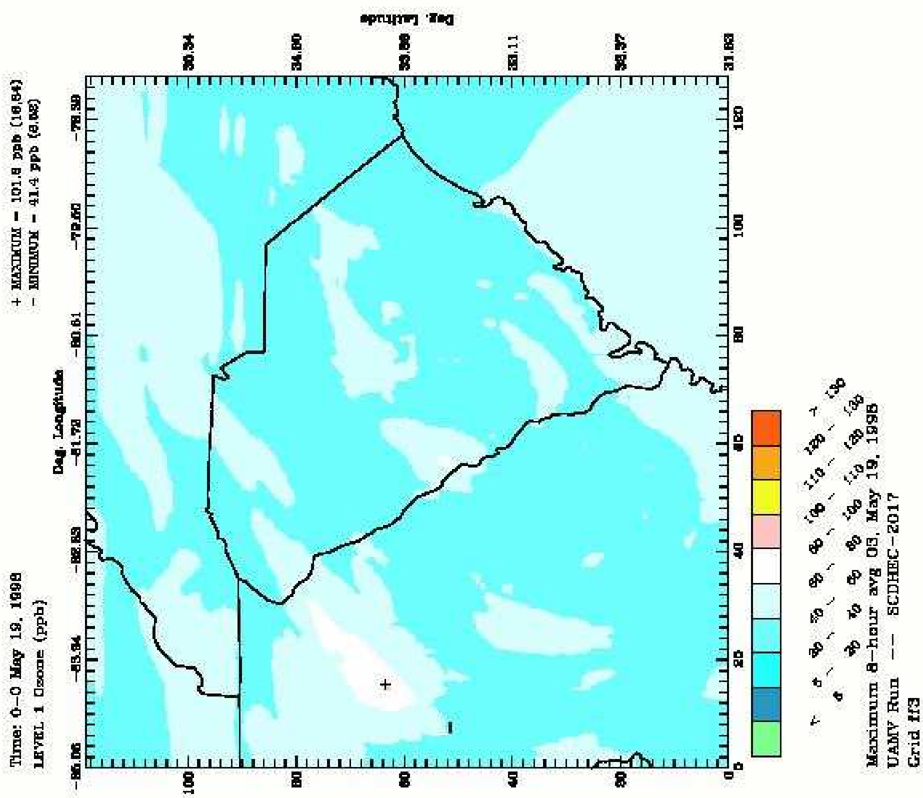
Time: 0-0 May 19, 1998
LEVEL 1 Ozone (ppb)
Deg. Longitude
Deg. Latitude
Maximum 8-hour avg 03, May 19, 1998
UAMV Run -- SCDHEC-2017
Grid #3

Figure 7-3d.

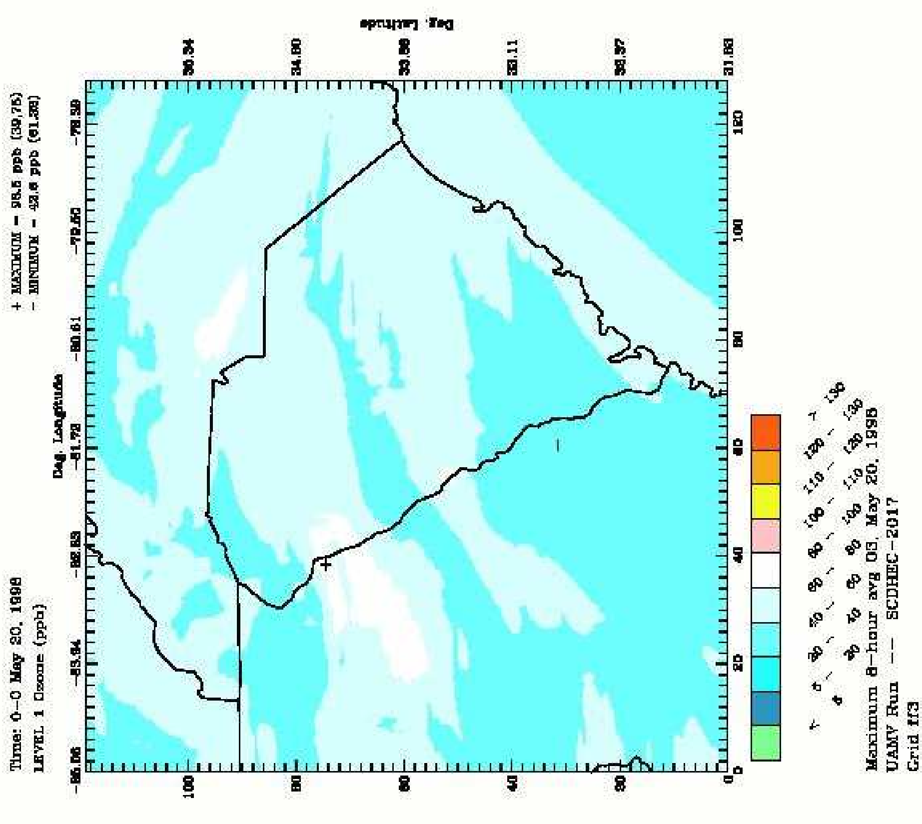

Figure 7-3e.

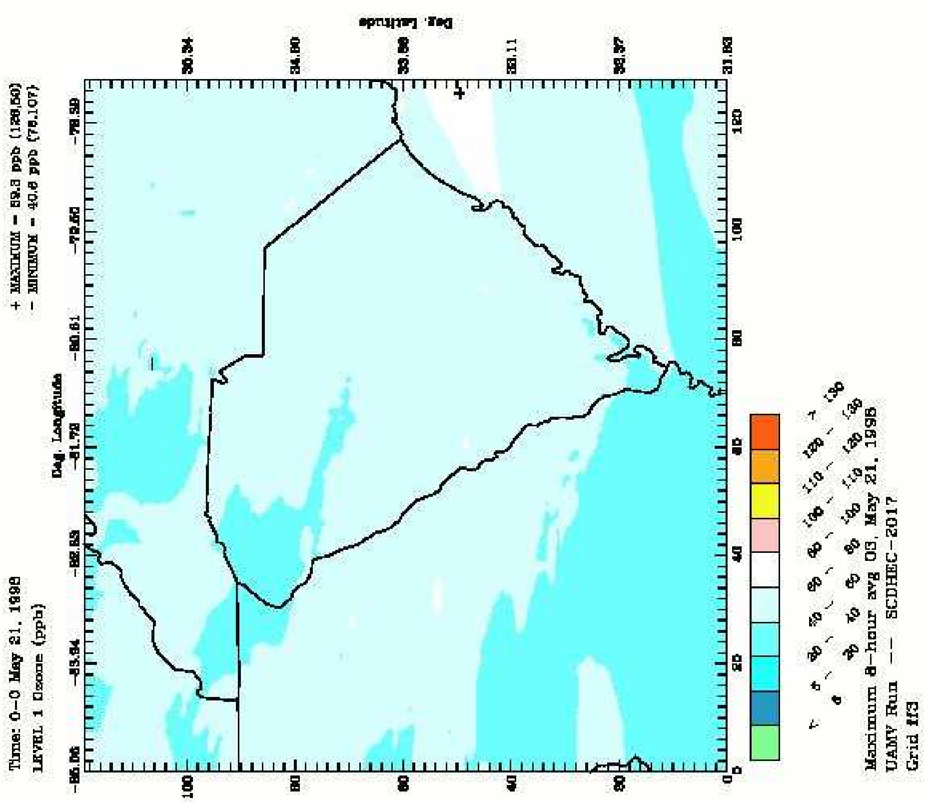
Time: 0-0 May 21, 1998
LEVEL 1 Ozone (ppb)
Deg. Longitude
Deg. Latitude
Maximum 8-hour avg O3, May 21, 1998
UAMV Run -- SCDHEC-2017
Grid #3

Figure 7-3f.

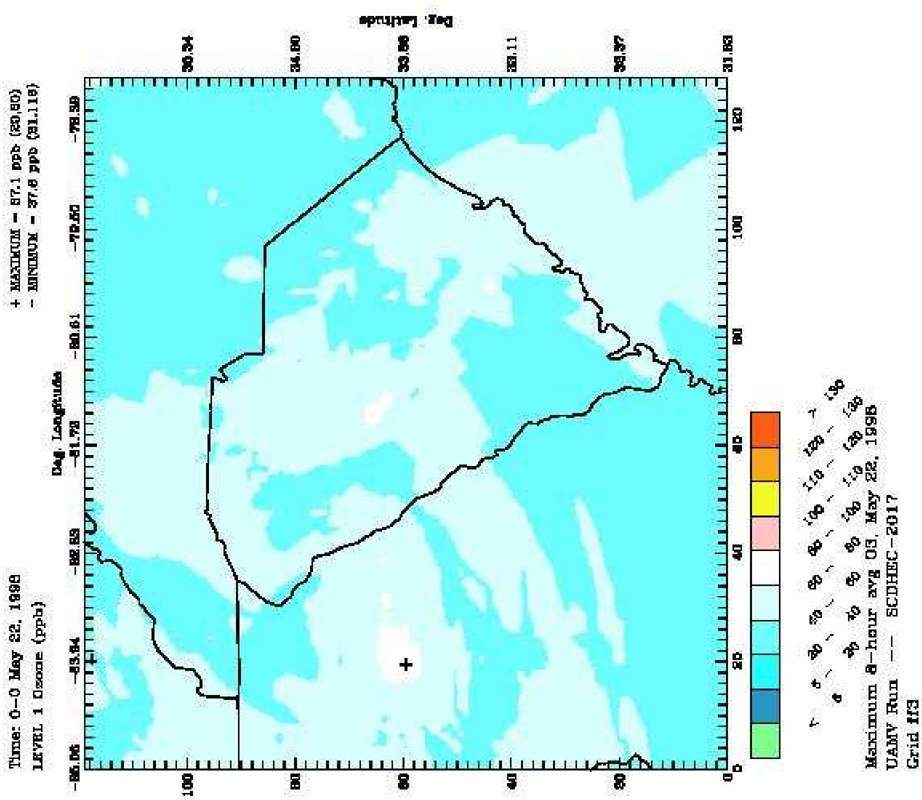
Time: 0-0 May 22, 1998
LEVEL 1 Ozone (ppb)
Deg. Longitude
Deg. Latitude
Maximum 8-hour avg O3, May 22, 1998
UAMV Run -- SCDHEC-2017
Grid #3

Figure 7-3g.

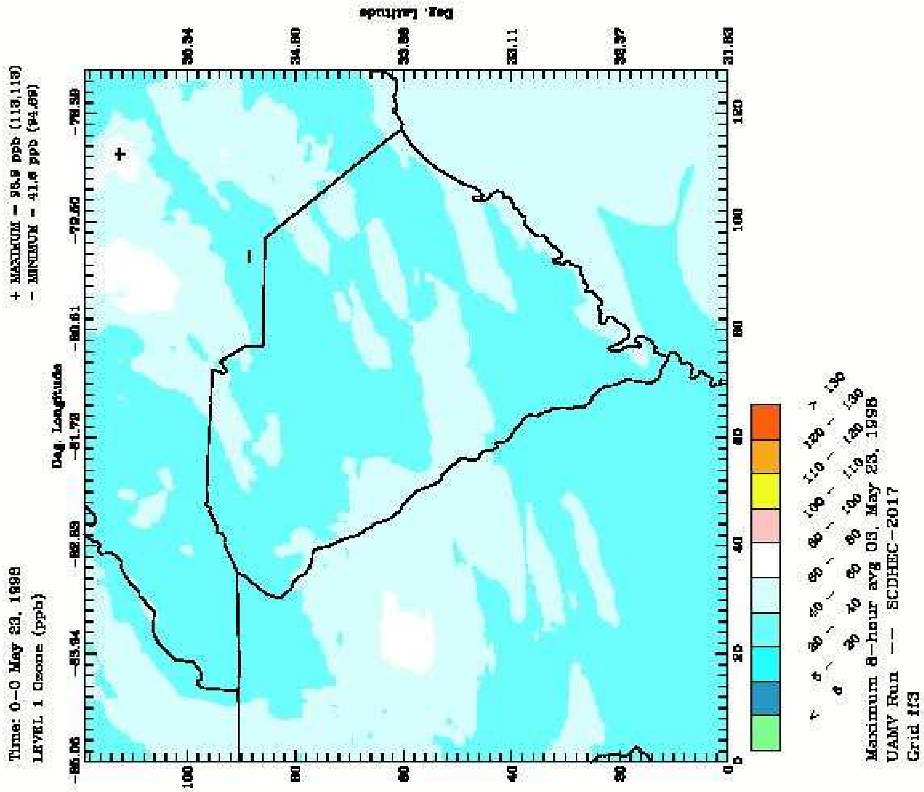
Time: 0-0 May 23, 1998
LEVEL 1 Ozone (ppb)
Deg. Longitude
Deg. Latitude
Maximum 8-hour avg O3, May 23, 1998
UAMV Run -- SCDHEC-2017
Grid #3

Figure 7-3h.

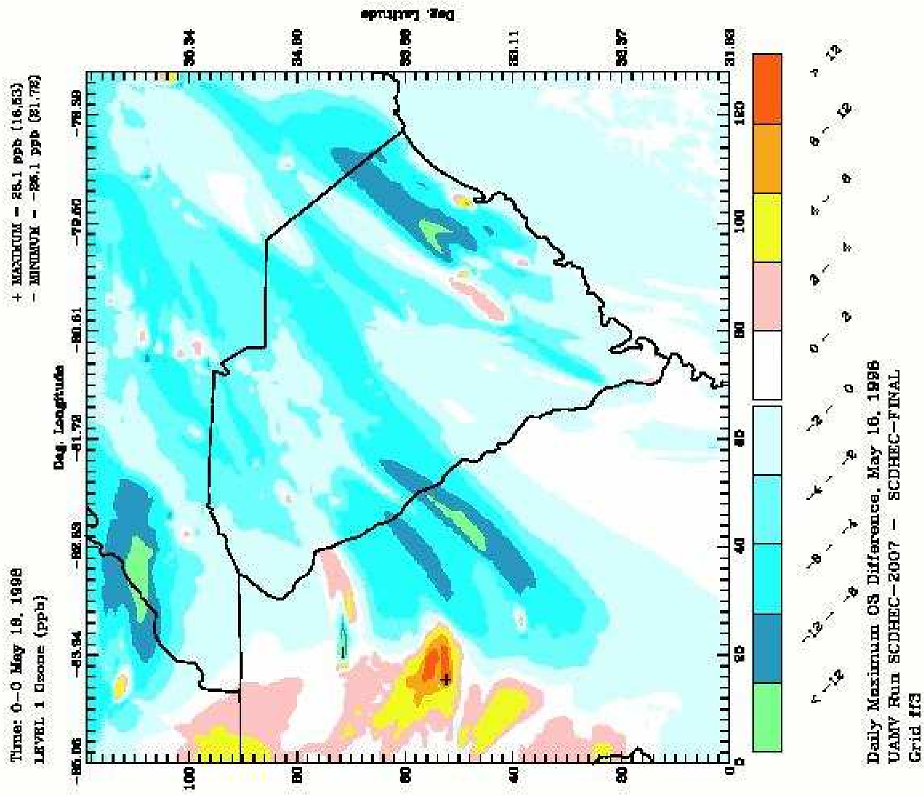
Deg. Longitude
Deg. Latitude
Daily Maximum O3 Difference, May 16, 1998
UAMV Run SCDHEC-2007 - SCDHEC-FINAL

Figure 7-4a.

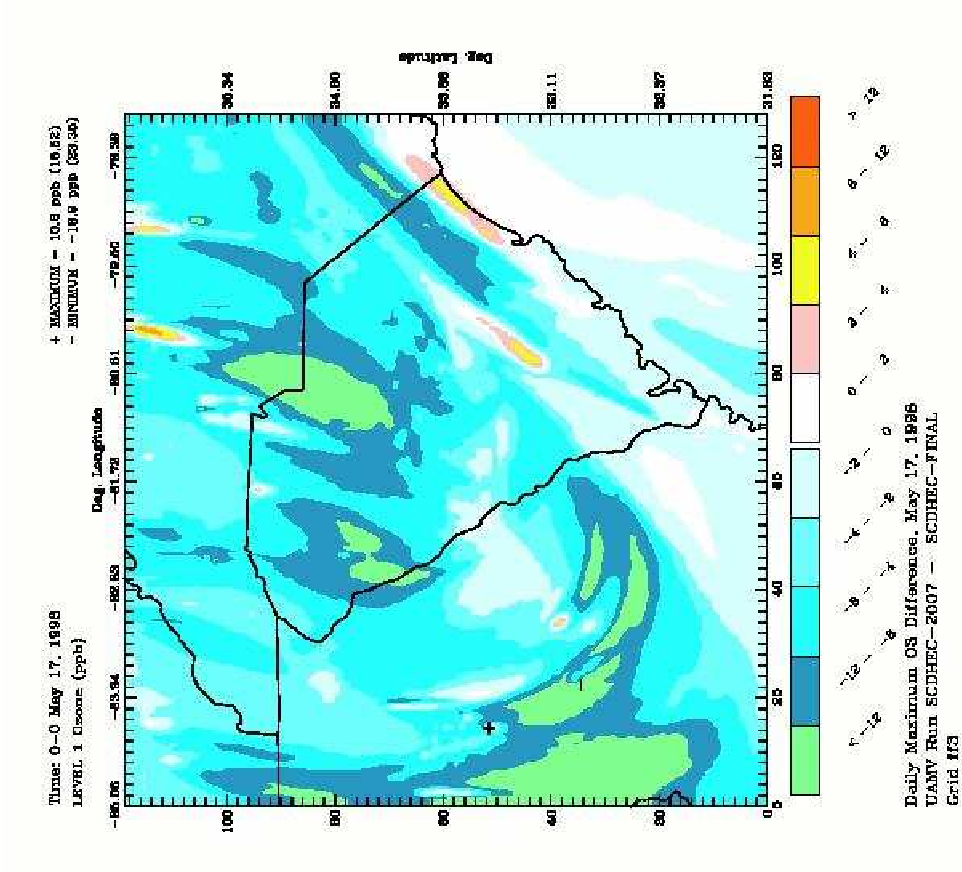
Time: 0-0 May 17, 1996
LEVEL 1 Ozone (ppb)
Deg. Longitude
Deg. Latitude
Daily Maximum O3 Difference, May 17, 1996
UAMV Run SCDHEC-2007 - SCDHEC-FINAL
Grid #3

Figure 7-4b.

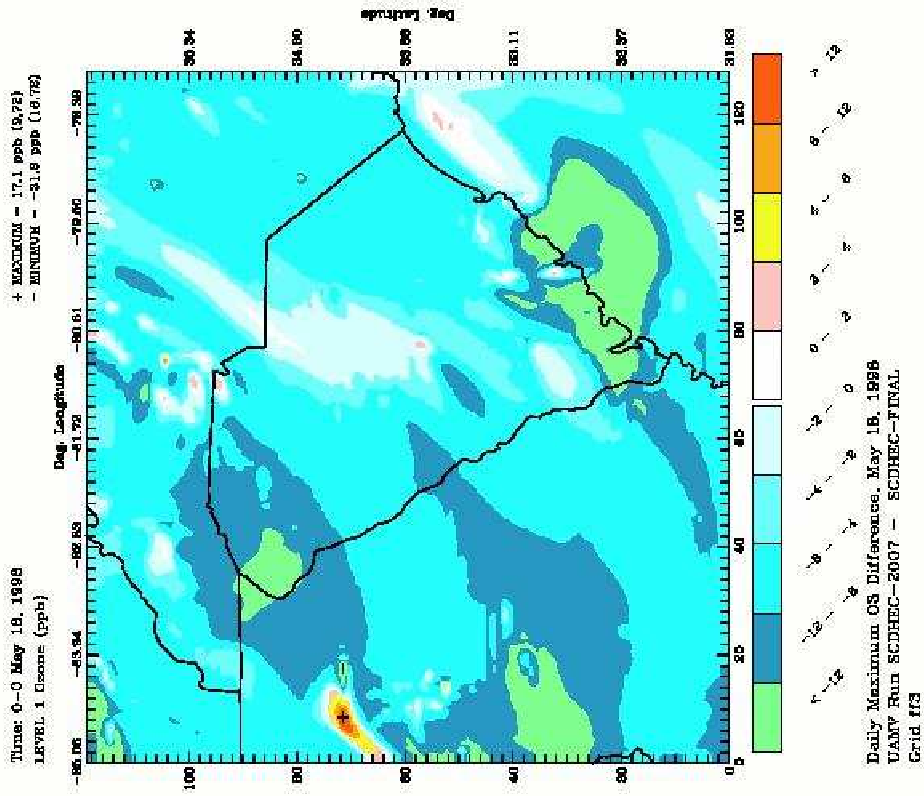
Time: 0-0 May 18, 1998
LEVEL 1 Ozone (ppb)
Deg. Longitude
Deg. Latitude
Daily Maximum OS Difference, May 18, 1998
UAMV Run SCDHEC-2007 - SCDHEC-FINAL

Figure 7-4c.

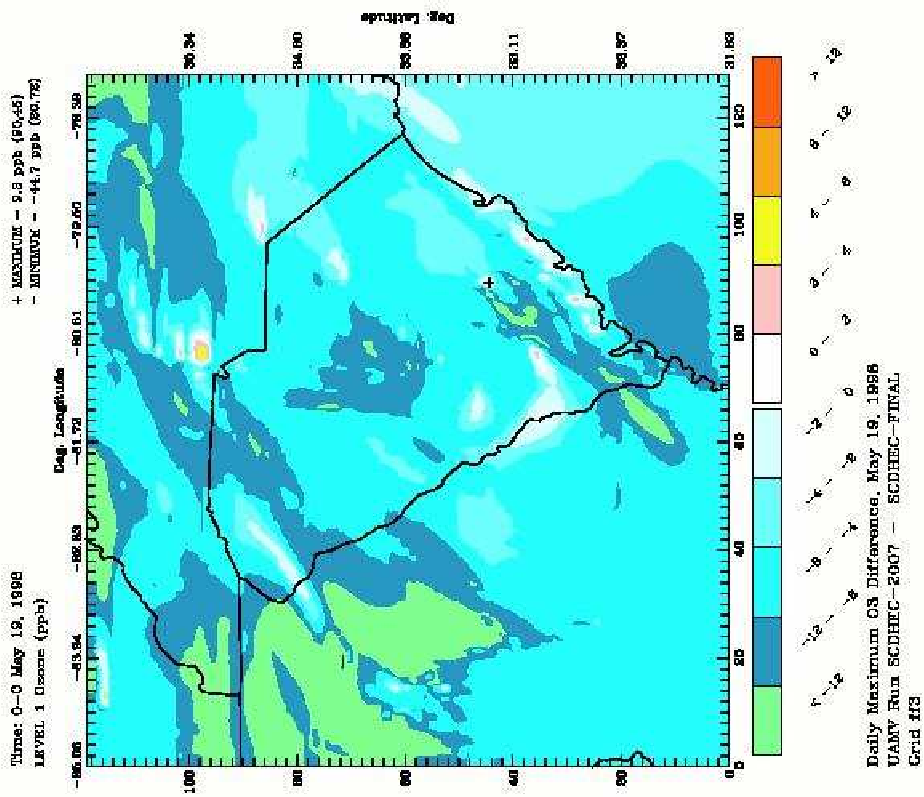
Time: 0-0 May 19, 1998
LEVEL 1 Ozone (ppb)
Deg. Longitude
Deg. Latitude
Daily Maximum O3 Difference, May 19, 1998
UAMV Run SCDHEC-2007 - SCDHEC-FINAL
Grid #3

Figure 7-4d.

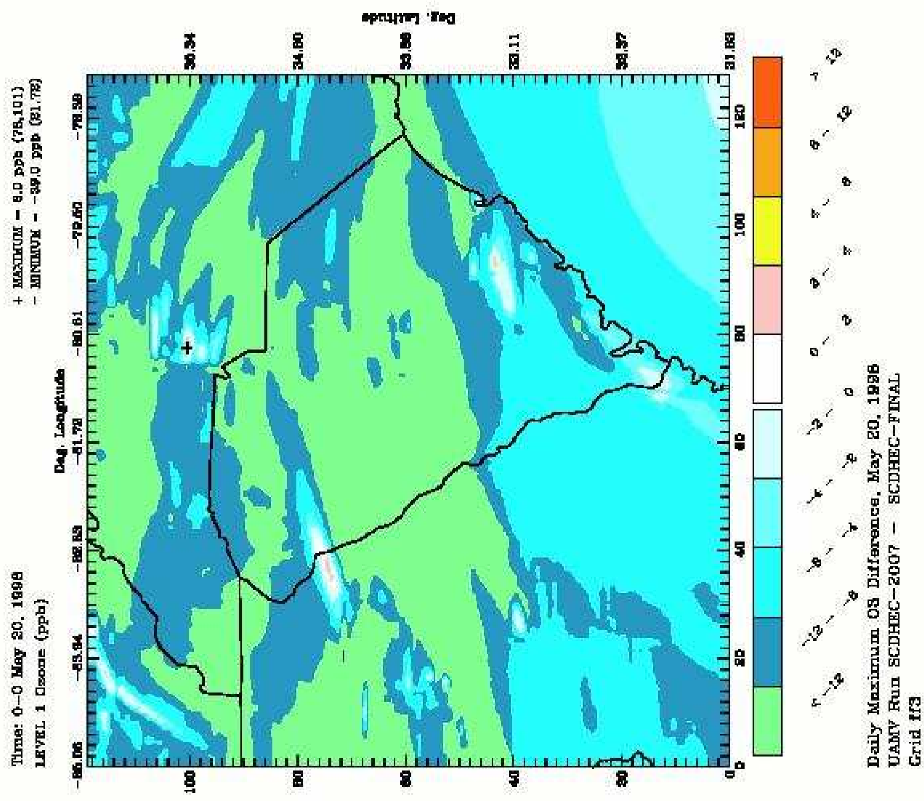
Time: 0-0 May 20, 1996
LEVEL 1 Ozone (ppb)
+ MAXIMUM = 5.0 ppb (78,101)
- MINIMUM = -39.0 ppb (81,72)
Deg. Longitude
Deg. Latitude
Daily Maximum O3 Difference, May 20, 1996
UAMV Run SCDHEC-2007 – SCDHEC-FINAL
Grid #3

Figure 7-4e.

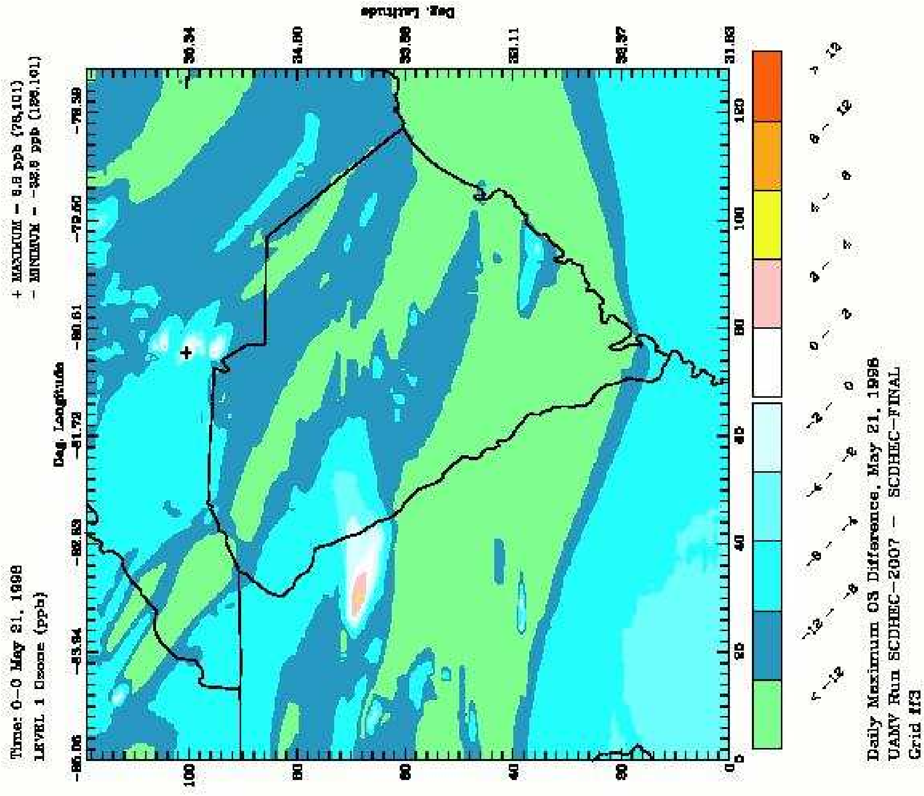
Daily Maximum O3 Difference, May 21, 1998
UAMV Run SCDHEC-2007 - SCDHEC-FINAL
Grid #3
Time: 0-0 May 21, 1998
LEVEL 1 Ozone (ppb)
Deg. Longitude
Deg. Latitude

Figure 7-4f.

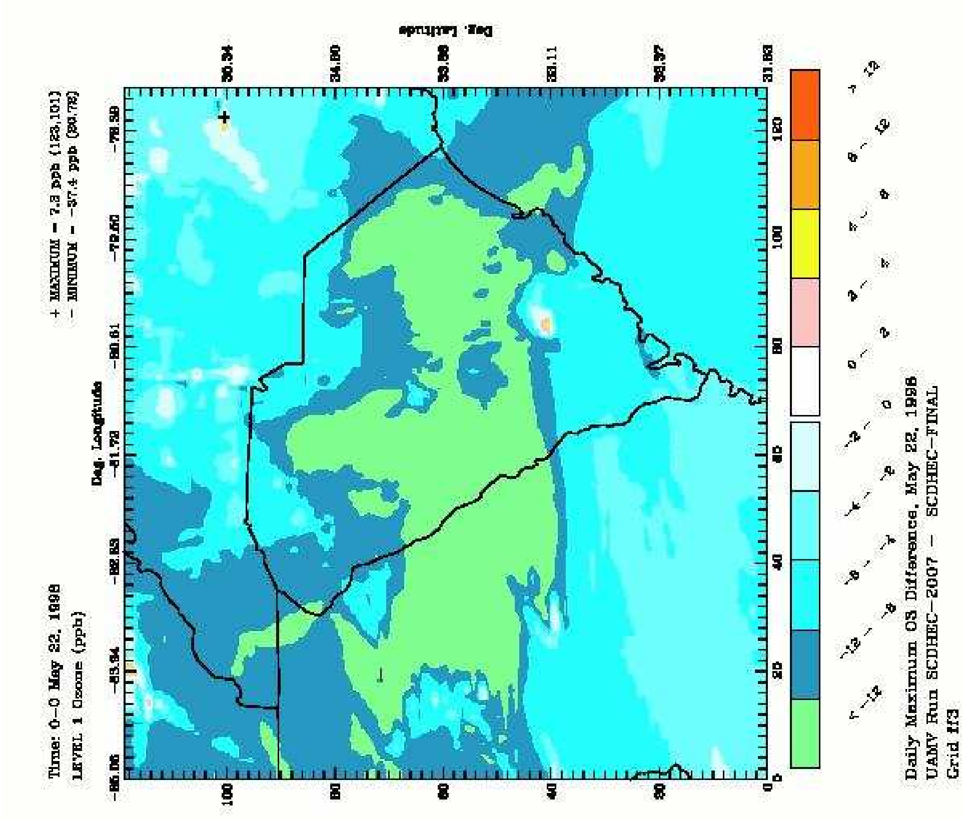
Time: 0-0 May 22, 1998
LEVEL 1 Ozone (ppb)
Deg. Longitude
Deg. Latitude
Daily Maximum O3 Difference, May 22, 1998
UAMV Run SCDHEC-2007 - SCDHEC-FINAL
Grid #3

Figure 7-4g.

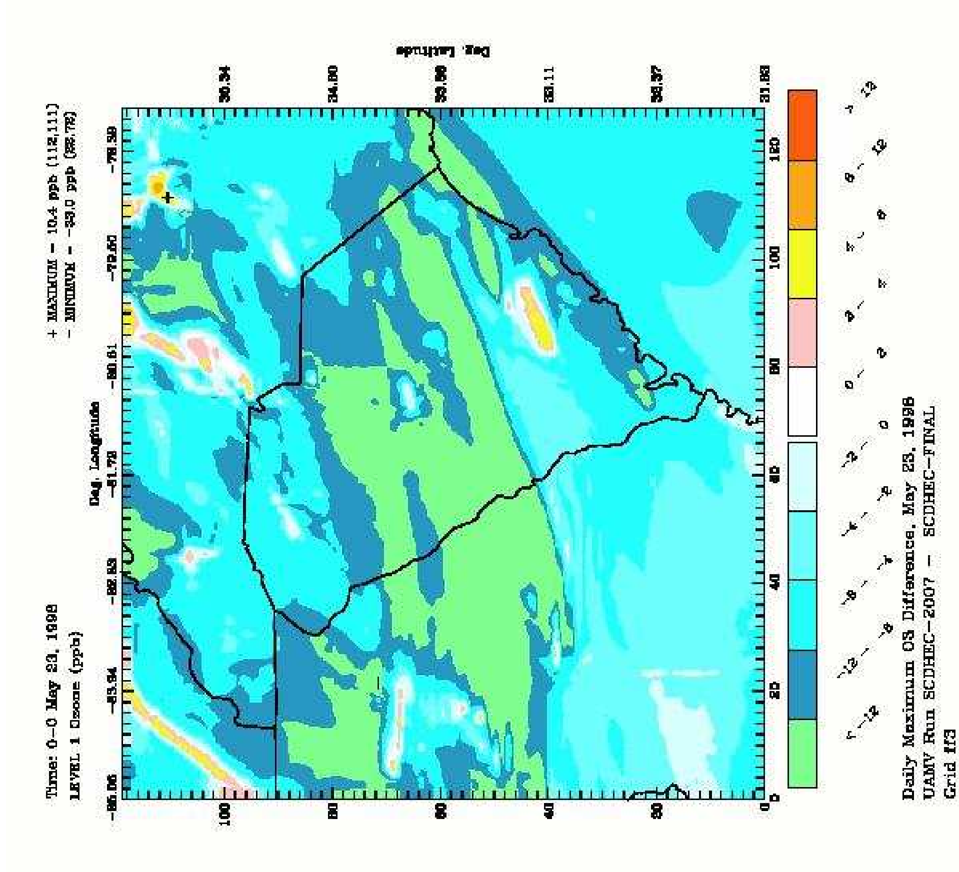
Time: 0-0 May 23, 1998
LEVEL 1 Ozone (ppb)
+ MAXIMUM = 10.4 ppb (112,111)
- MINIMUM = -33.0 ppb (32,75)
Deg. Longitude
Deg. Latitude
Daily Maximum O3 Difference, May 23, 1998
UAMV Run SCDHEC-2007 - SCDHEC-FINAL
Grid #3

Figure 7-4h.

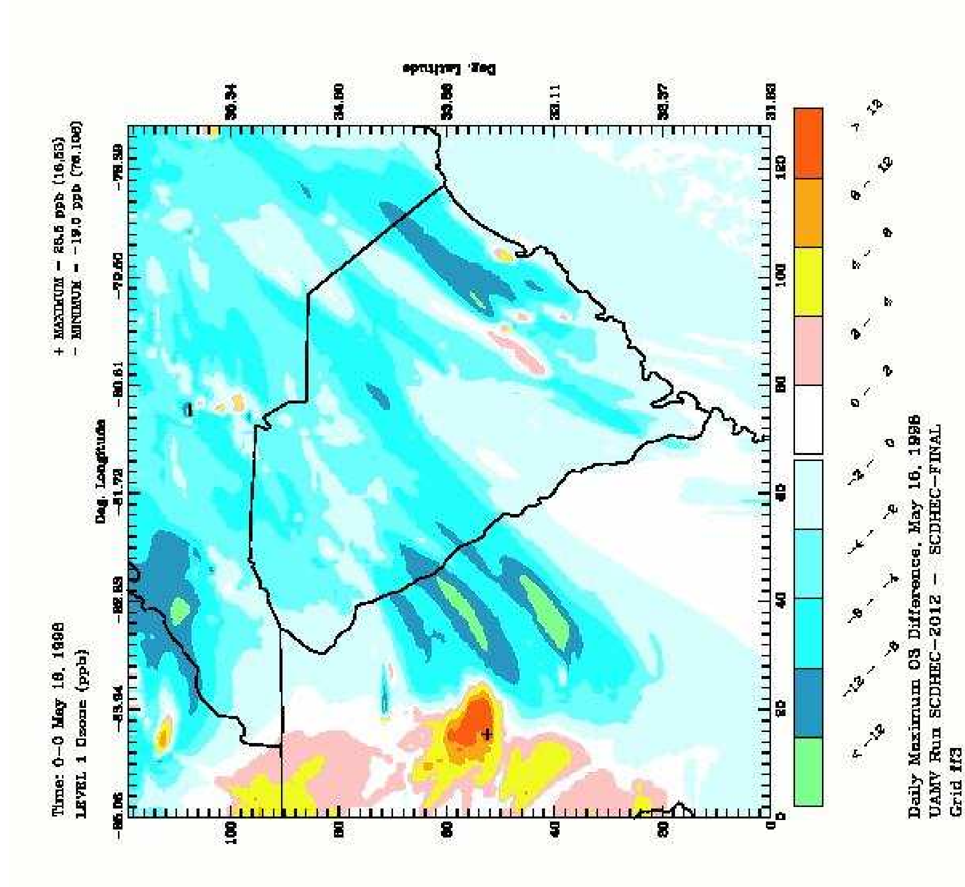
Time: 0-0 May 16, 1998
LEVEL 1 Ozone (ppb)
+ MAXIMUM = 25.5 ppb (16,53)
- MINIMUM = -19.0 ppb (76,106)
Deg. Longitude
Deg. Latitude
Daily Maximum O3 Difference, May 16, 1998
UAMV Run SCDHEC-2012 – SCDHEC-FINAL
Grid #3

Figure 7-5a.

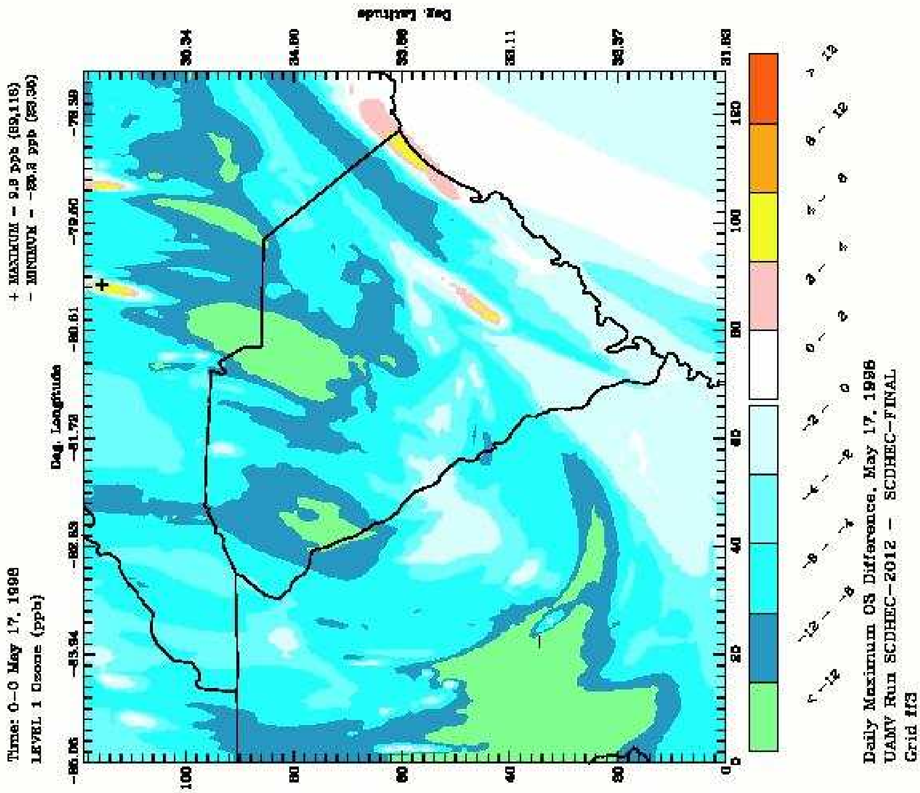
Time: 0-0 May 17, 1998
LEVEL 1 Ozone (ppb)
Deg. Longitude
Deg. Latitude
Daily Maximum O3 Difference, May 17, 1998
UAMV Run SCDHEC-2012 - SCDHEC-FINAL
Grid #f3

Figure 7-5b.

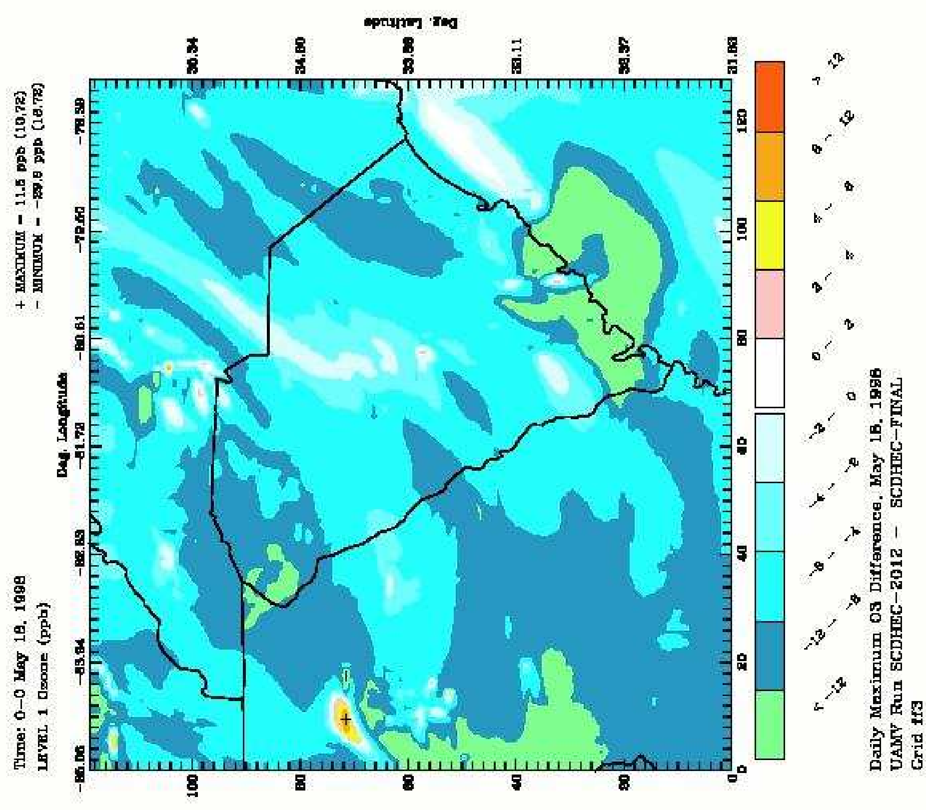
Daily Maximum O3 Difference, May 18, 1998
UAMV Run SCDHEC-2012 - SCDHEC-FINAL
Grid ff3
Time: 0-0 May 18, 1998
LEVEL 1 Ozone (ppb)
Deg. Longitude
Deg. Latitude

Figure 7-5c.

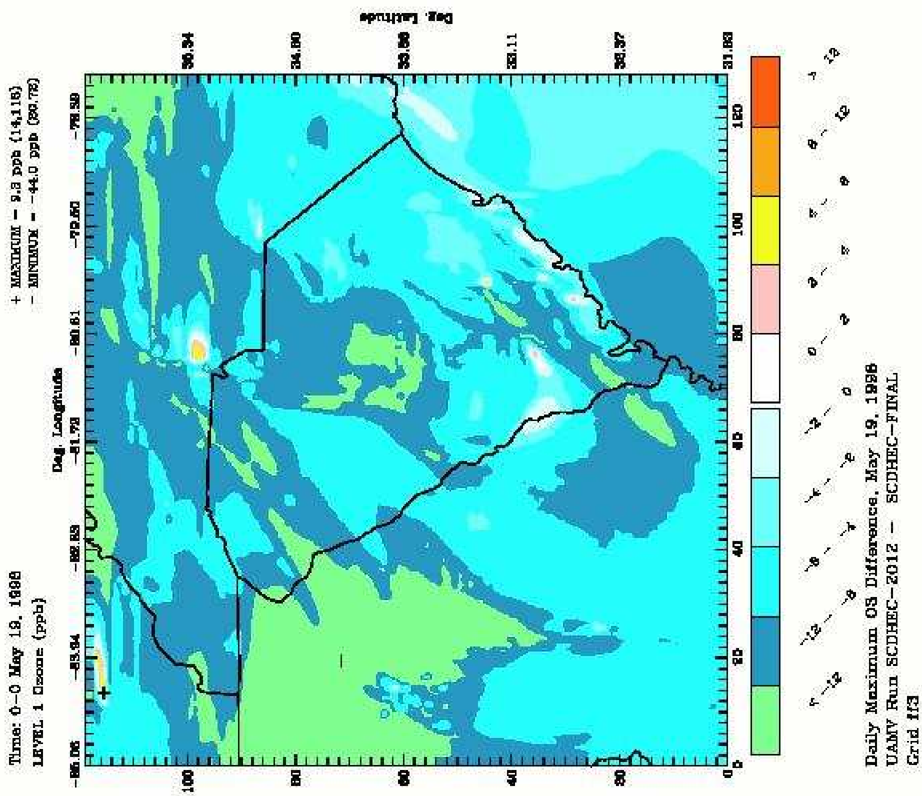
Time: 0-0 May 19, 1996
LEVEL 1 Ozone (ppb)
+ MAXIMUM = 9.3 ppb (14,116)
- MINIMUM = -44.0 ppb (86,72)
Deg. Longitude
Deg. Latitude
Daily Maximum O3 Difference, May 19, 1996
UAMV Run SCDHEC-2012 - SCDHEC-FINAL
Grid #3

Figure 7-5d.

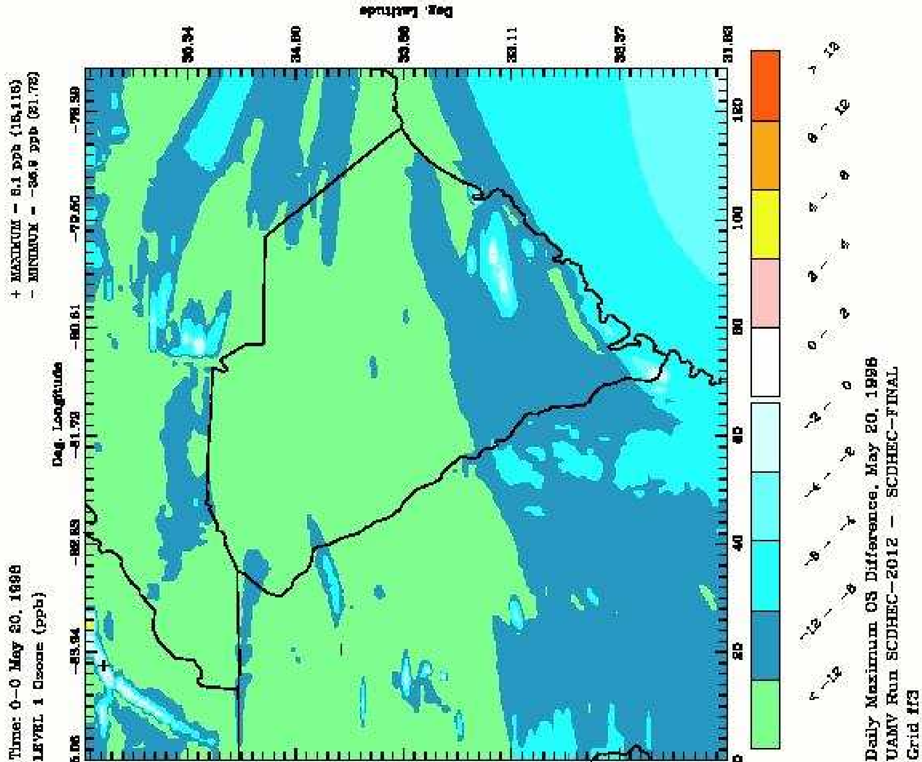
Daily Maximum O3 Difference, May 20, 1996
UAMV Run SCDHEC-2012 – SCDHEC-FINAL
Grid #3

Figure 7-5e.

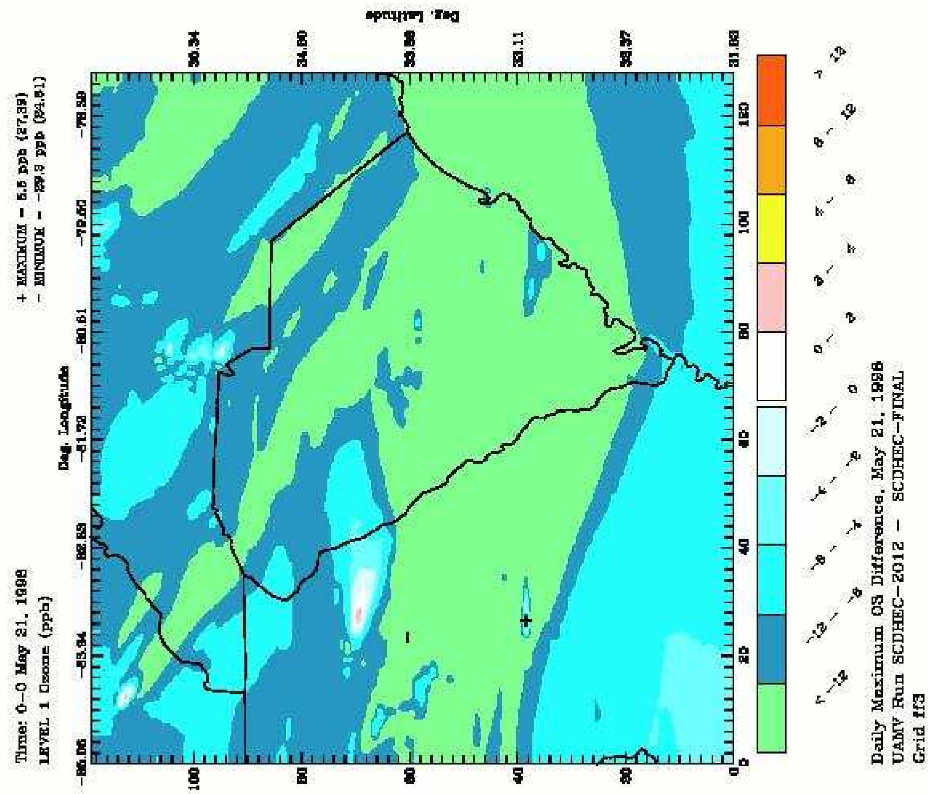
Time: 0-0 May 21, 1998
LEVEL 1 Ozone (ppb)
Deg. Longitude
Deg. Latitude
Daily Maximum O3 Difference, May 21, 1998
UAMV Run SCDHEC-2012 - SCDHEC-FINAL

Figure 7-5f.

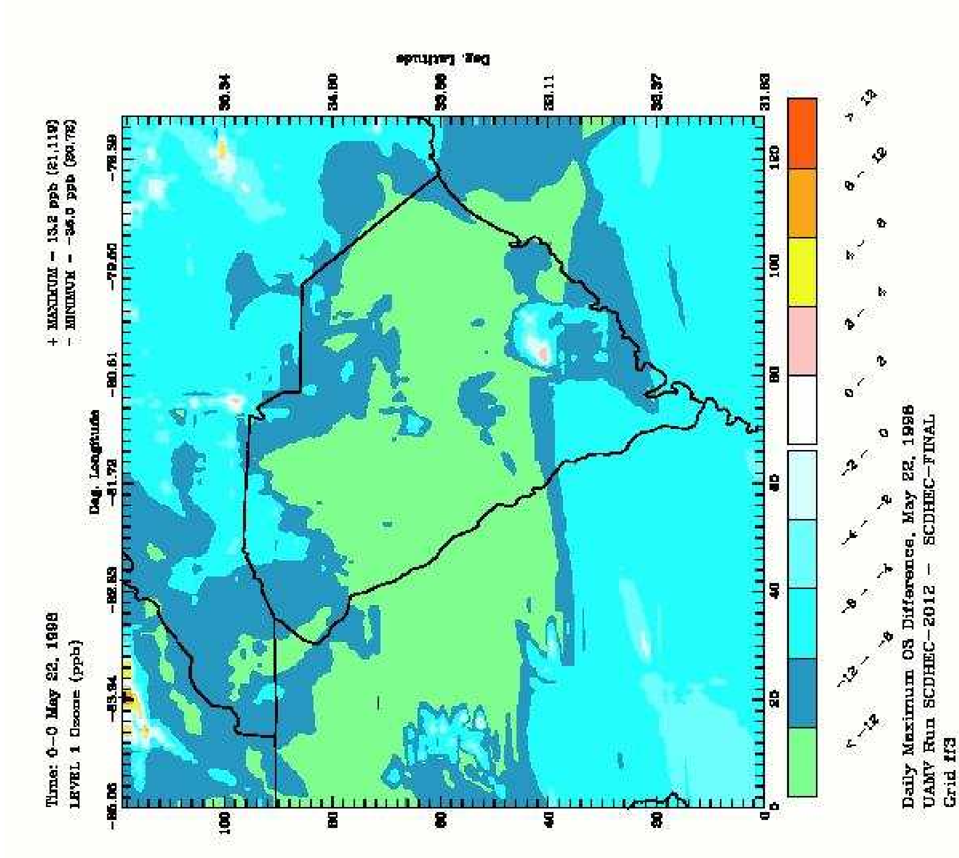
Time: 0-0 May 22, 1998
LEVEL 1 Ozone (ppb)
Deg. Longitude
Deg. Latitude
Daily Maximum O3 Difference, May 22, 1998
UAMV Run SCDHEC-2012 - SCDHEC-FINAL

Figure 7-5g.

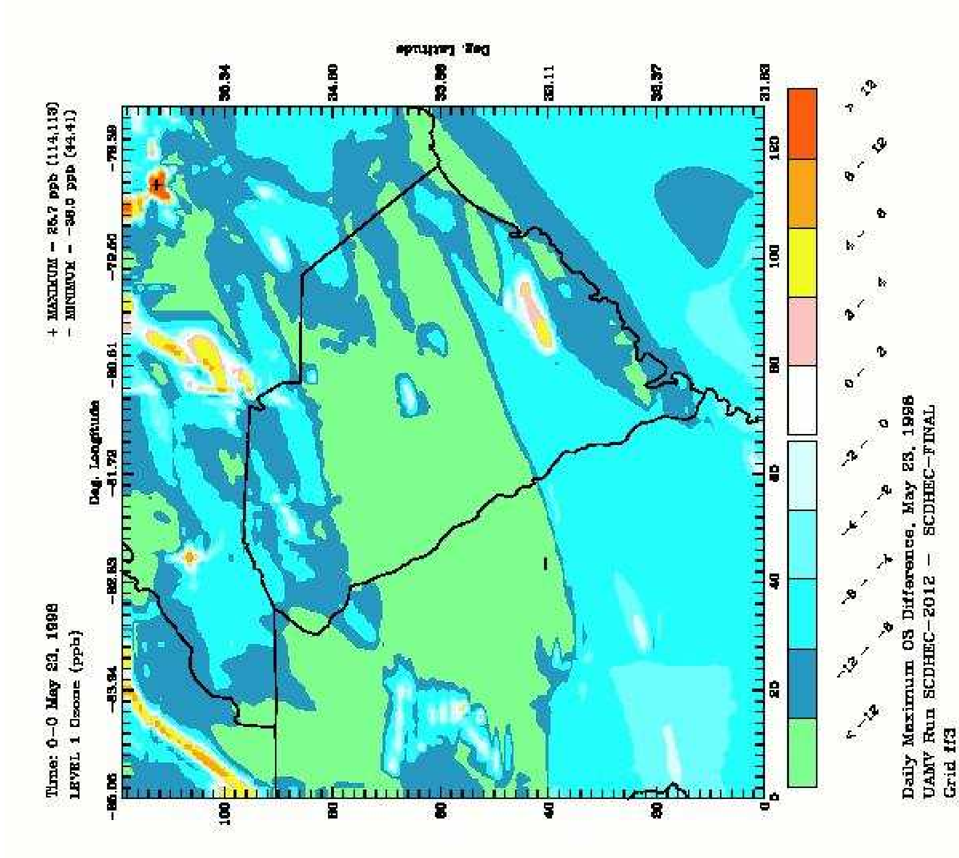
Time: 0-0 May 23, 1998
LEVEL 1 Ozone (ppb)
+ MAXIMUM = 25.7 ppb (114,113)
- MINIMUM = -38.0 ppb (44,41)
Deg. Longitude
Deg. Latitude
Daily Maximum O3 Difference, May 23, 1998
UAMV Run SCDHEC-2012 - SCDHEC-FINAL
Grid #3

Figure 7-5h.

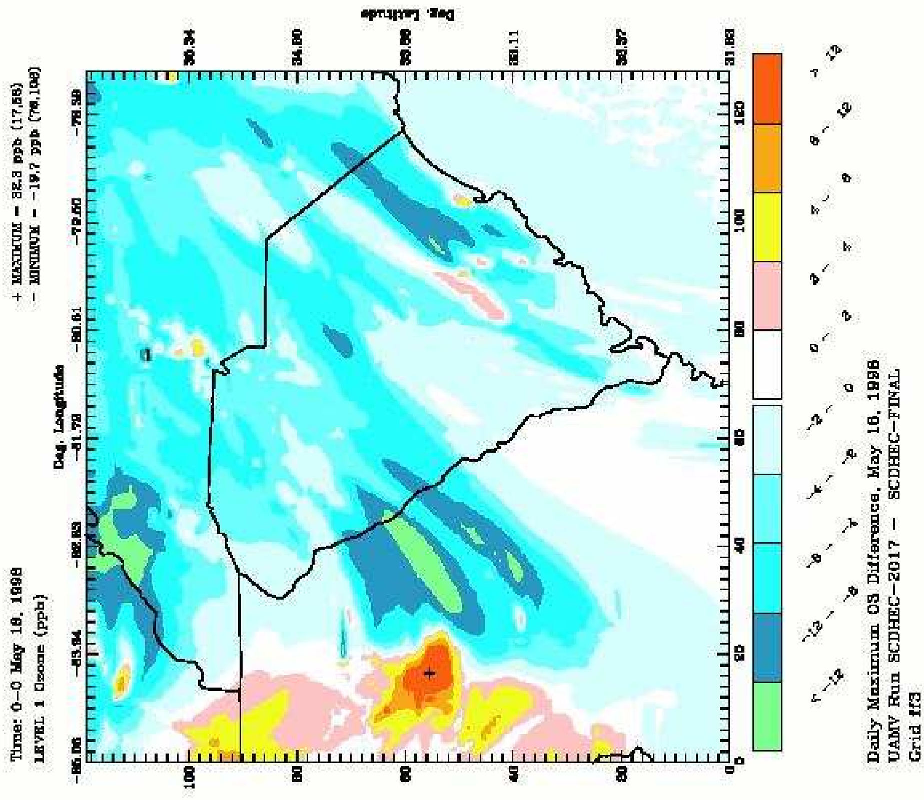
Time: 0-0 May 16, 1998
LEVEL 1 Ozone (ppb)
+ MAXIMUM = 32.3 ppb (17,58)
- MINIMUM = -19.7 ppb (76,106)
Deg. Longitude
Deg. Latitude
Daily Maximum O3 Difference, May 16, 1998
UAMV Run SCDHEC-2017 - SCDHEC-FINAL
Grid #3

Figure 7-6a.

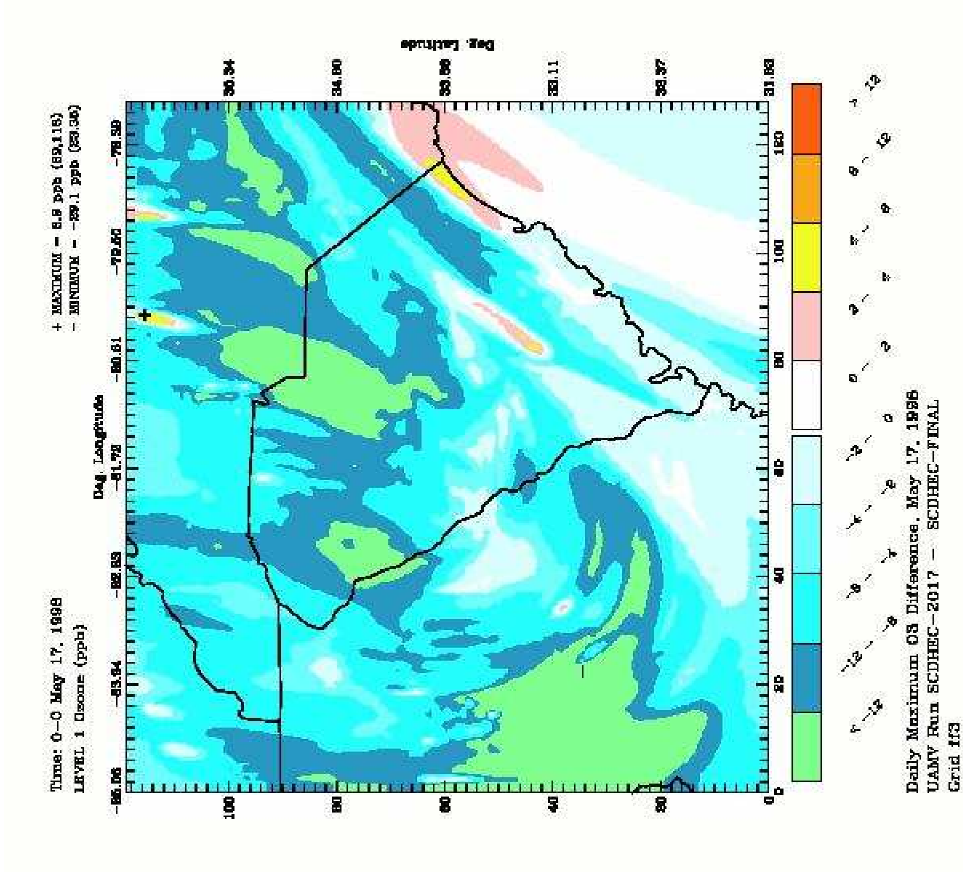
Time: 0-0 May 17, 1995
LEVEL 1 Ozone (ppb)
Deg. Longitude
Deg. Latitude
Daily Maximum O3 Difference. May 17, 1995
UAMV Run SCDHEC-2017 - SCDHEC-FINAL

Figure 7-6b.

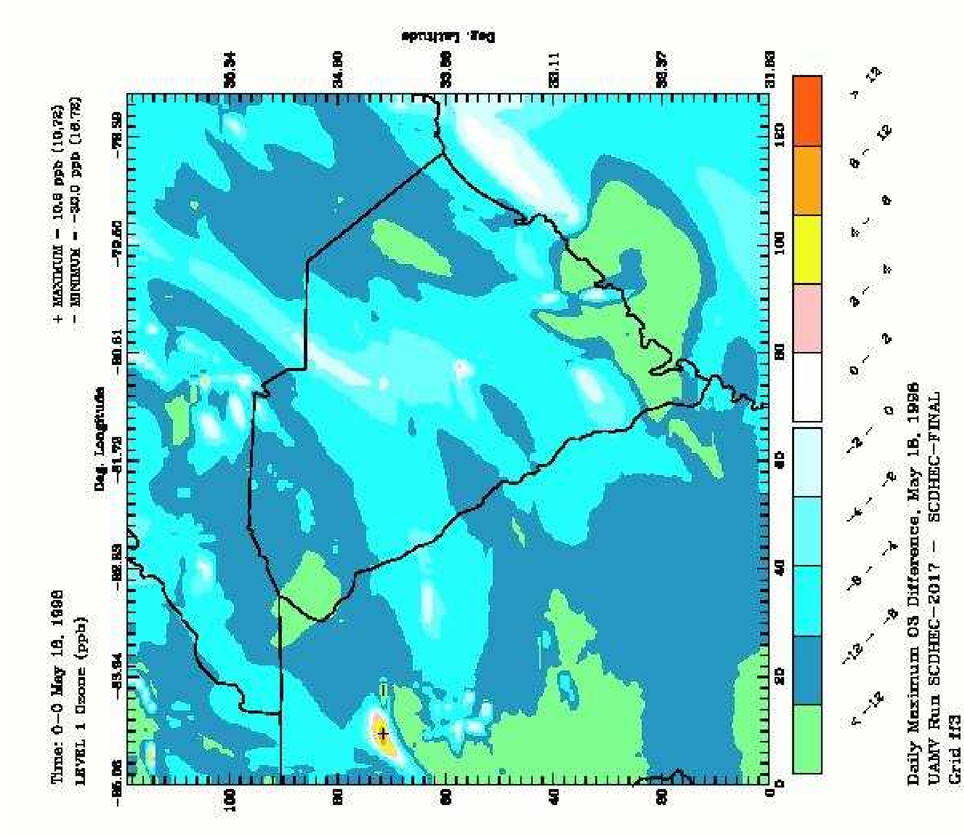
Daily Maximum O3 Difference, May 18, 1998
UAMV Run SCDHEC-2017 - SCDHEC-FINAL
Grid ff3

Figure 7-6c.

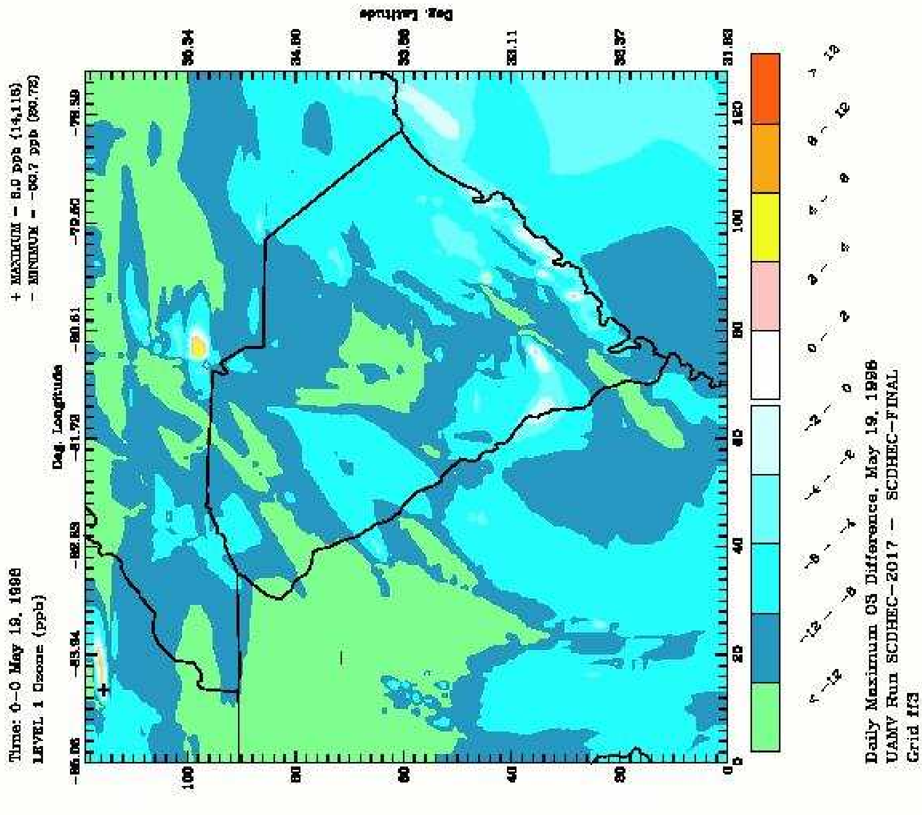
Daily Maximum O3 Difference, May 19, 1998
UAMV Run SCDHEC-2017 – SCDHEC-FINAL
Grid ff3
Time: 0-0 May 19, 1998
LEVEL 1 Ozone (ppb)
+ MAXIMUM = 5.0 ppb (14,118)
– MINIMUM = -33.7 ppb (80,72)
Deg. Longitude
Deg. Latitude

Figure 7-6d.

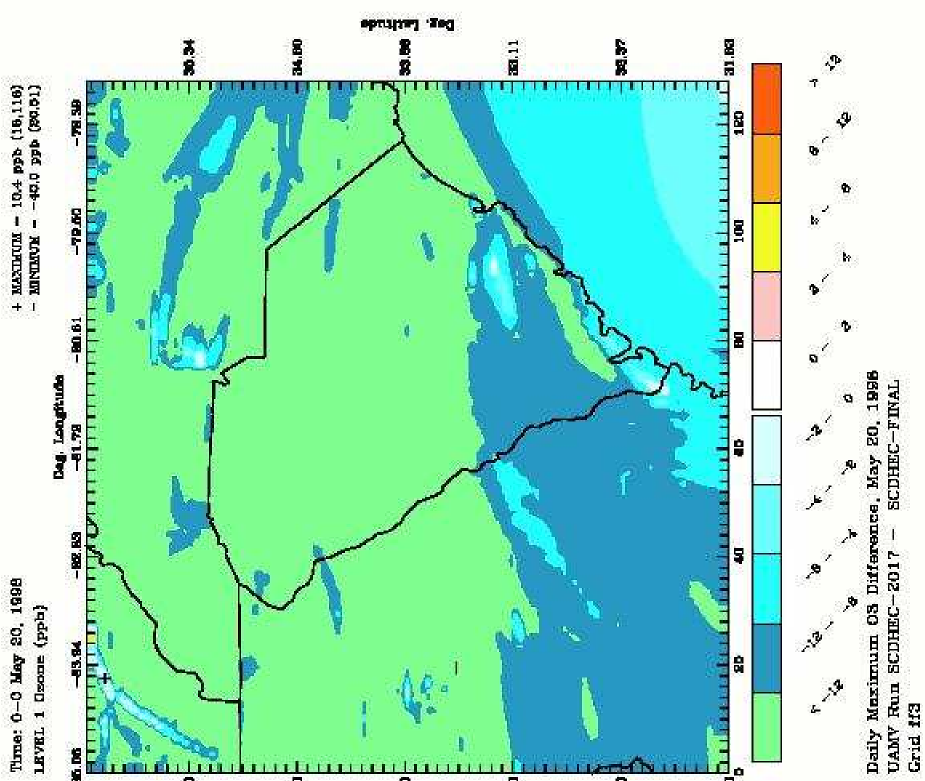
Time: 0-0 May 20, 1998
LEVEL 1 Ozone (ppb)
Deg. Longitude
Deg. Latitude
Daily Maximum O3 Difference, May 20, 1998
UAMV Run SCDHEC-2017 - SCDHEC-FINAL

Figure 7-6e.

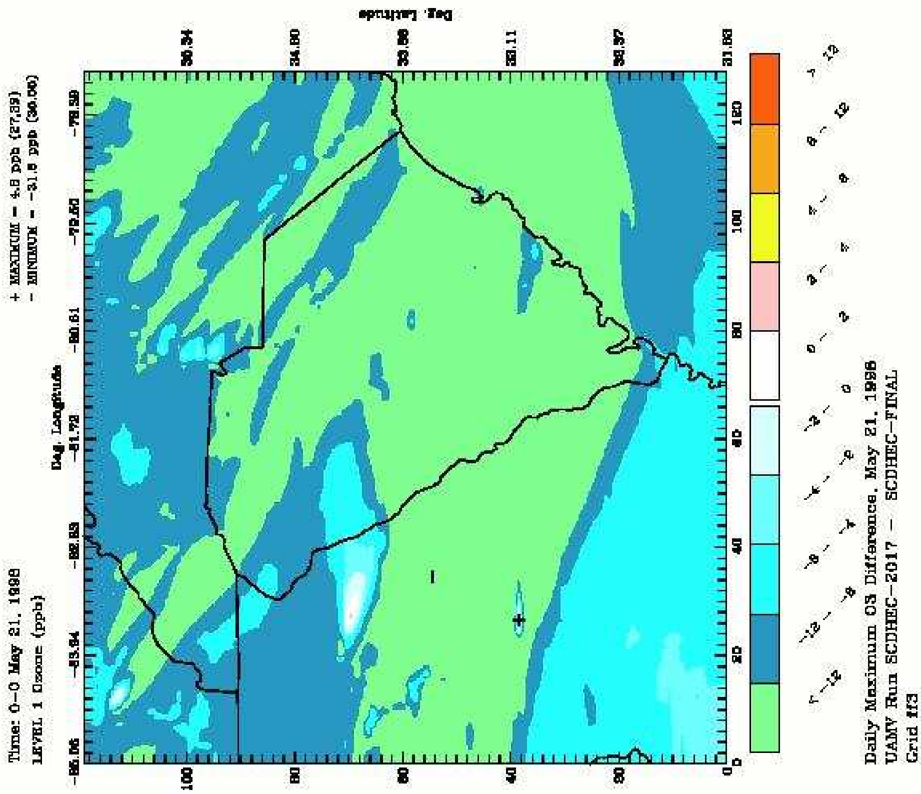
Time: 0-0 May 21, 1998
LEVEL 1 Ozone (ppb)
Deg. Longitude
Deg. Latitude
Daily Maximum O3 Difference, May 21, 1998
UAMV Run SCDHEC-2017 - SCDHEC-FINAL
Grid #3

Figure 7-6f.

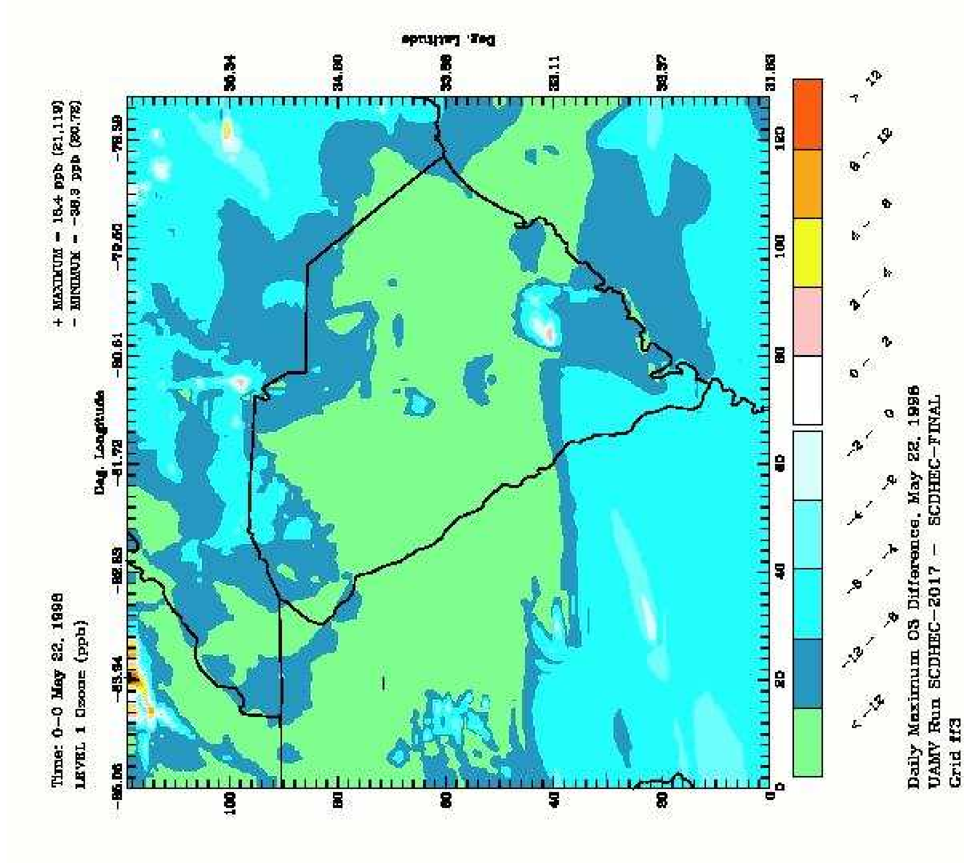
Time: 0-0 May 22, 1996
LEVEL 1 Ozone (ppb)
+ MAXIMUM = 15.4 ppb (21,119)
- MINIMUM = -38.3 ppb (30,72)
Deg. Longitude
Deg. Latitude
Daily Maximum O3 Difference, May 22, 1996
UAMV Run SCDHEC-2017 - SCDHEC-FINAL
Grid #3

Figure 7-6g.

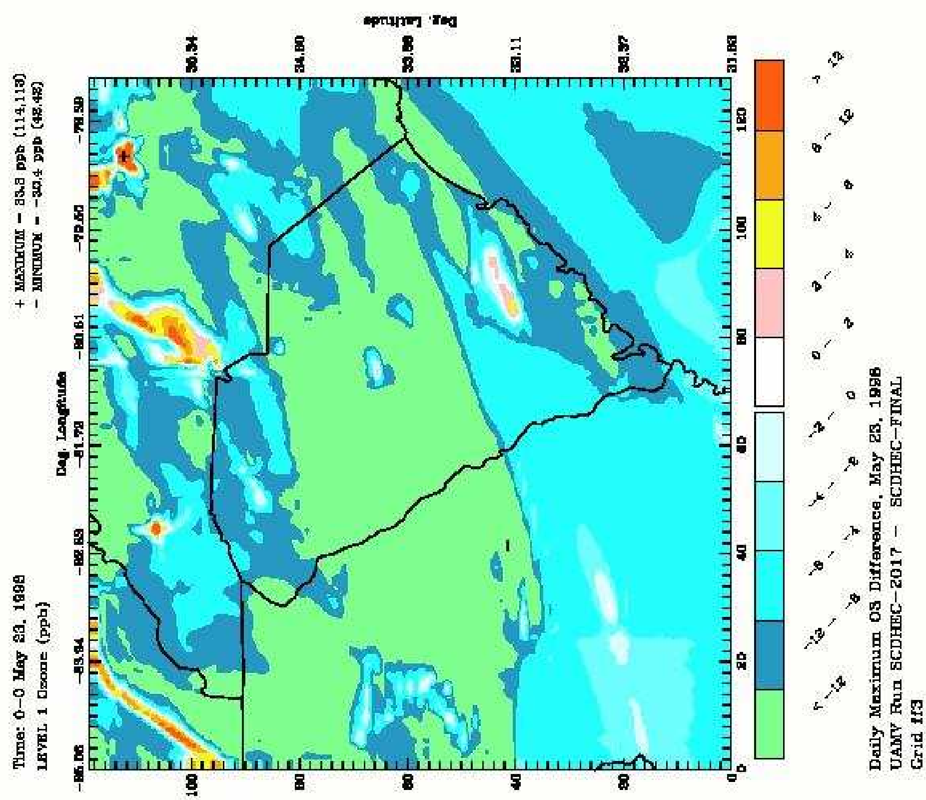
Daily Maximum O3 Difference, May 23, 1996
UAMV Run SCDHEC-2017 - SCDHEC-FINAL
Grid #3
Time: 0-0 May 23, 1996
LEVEL 1 Ozone (ppb)
Deg. Longitude
Deg. Latitude

Figure 7-6h.

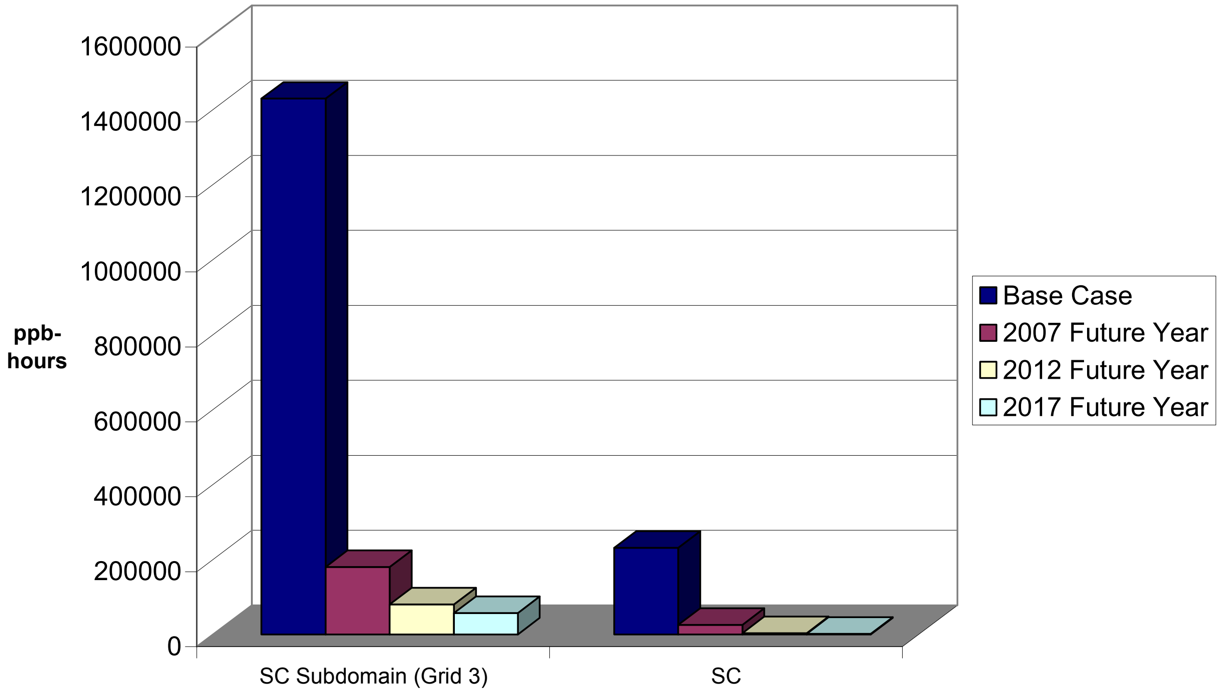

Figure 7-7a. Future year and base year ozone exposure for 18 – 22 May.

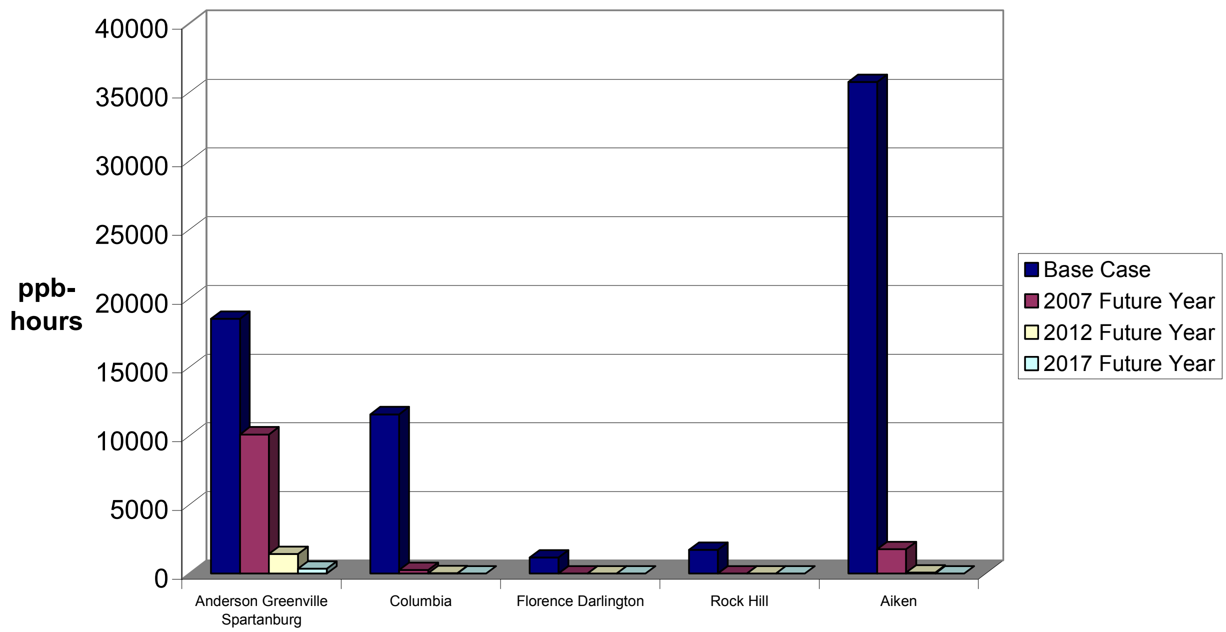

Figure 7-7b. Future year and base year ozone exposure for 18 – 22 May.

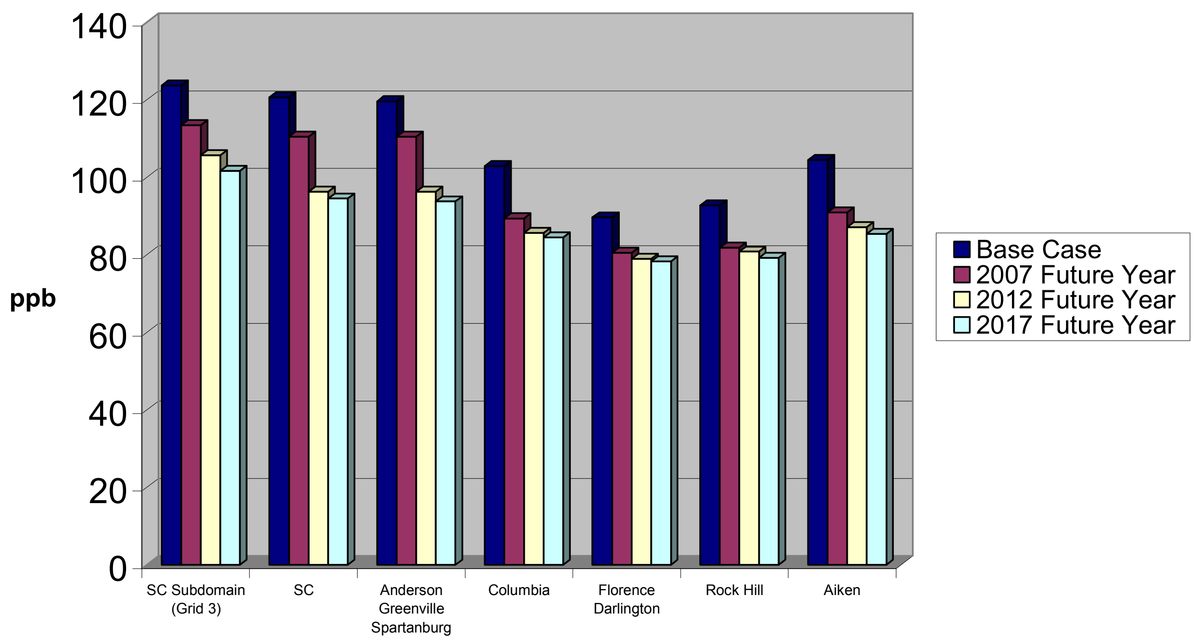

Figure 7-8. Future year and base year maximum 8-hour ozone values, 18 – 22 May.

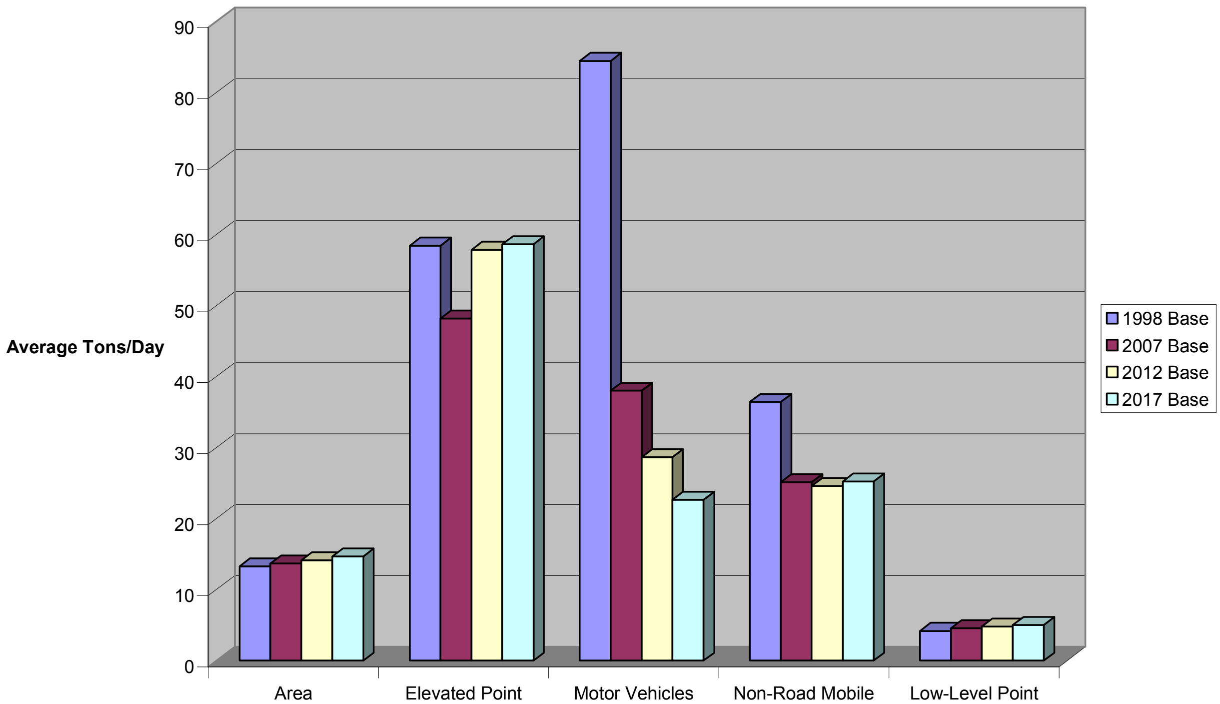

Figure 7-9a. Anderson, Greenville, Spartanburg area NO_x episode emissions.

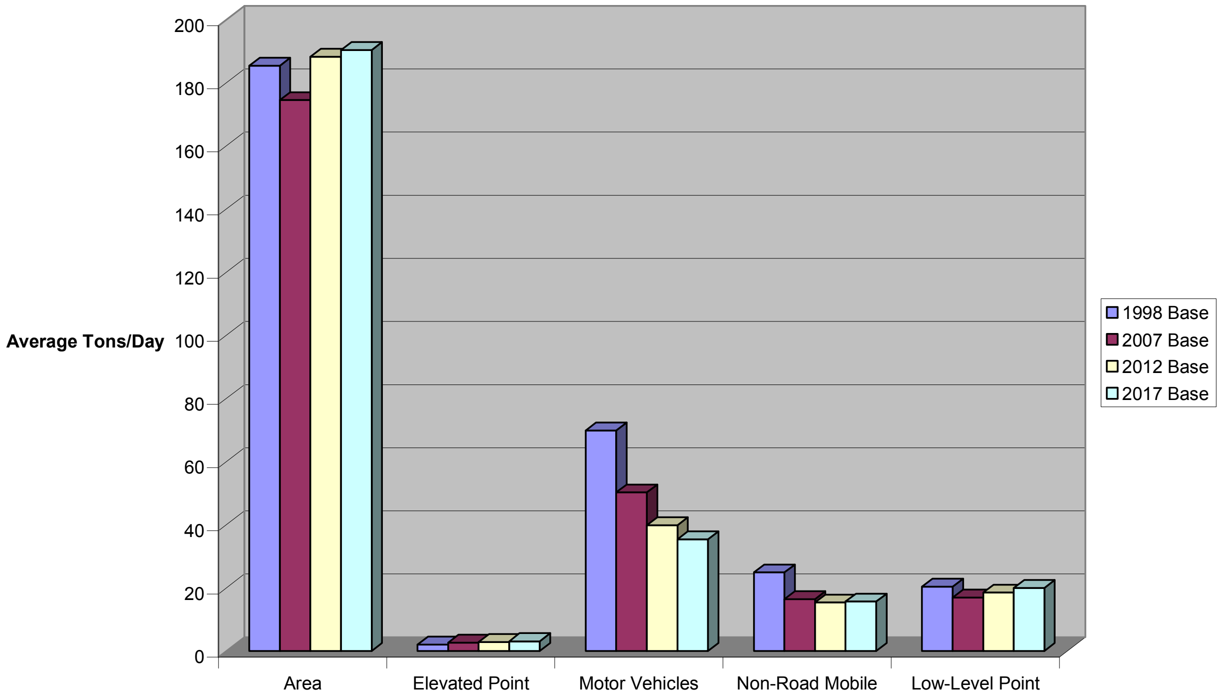

Figure 7-9b. Anderson, Greenville, Spartanburg area VOC episode emissions.

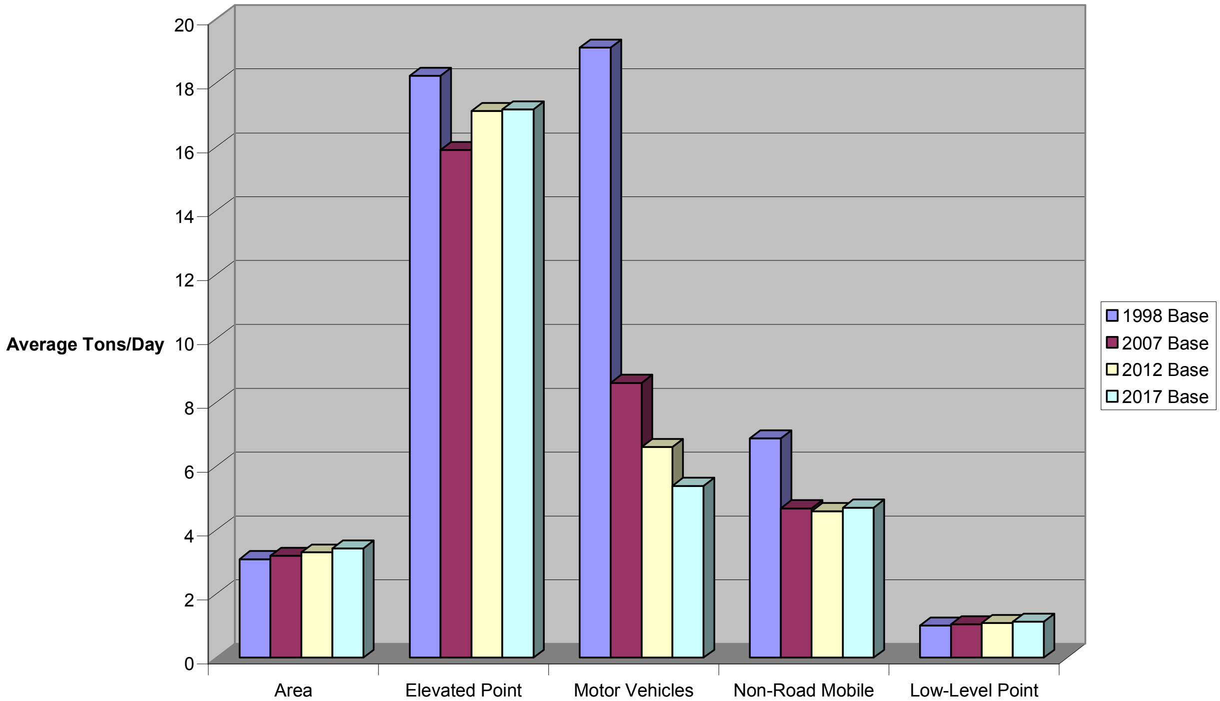

Figure 7-9c. Anderson area NO_x episode emissions.

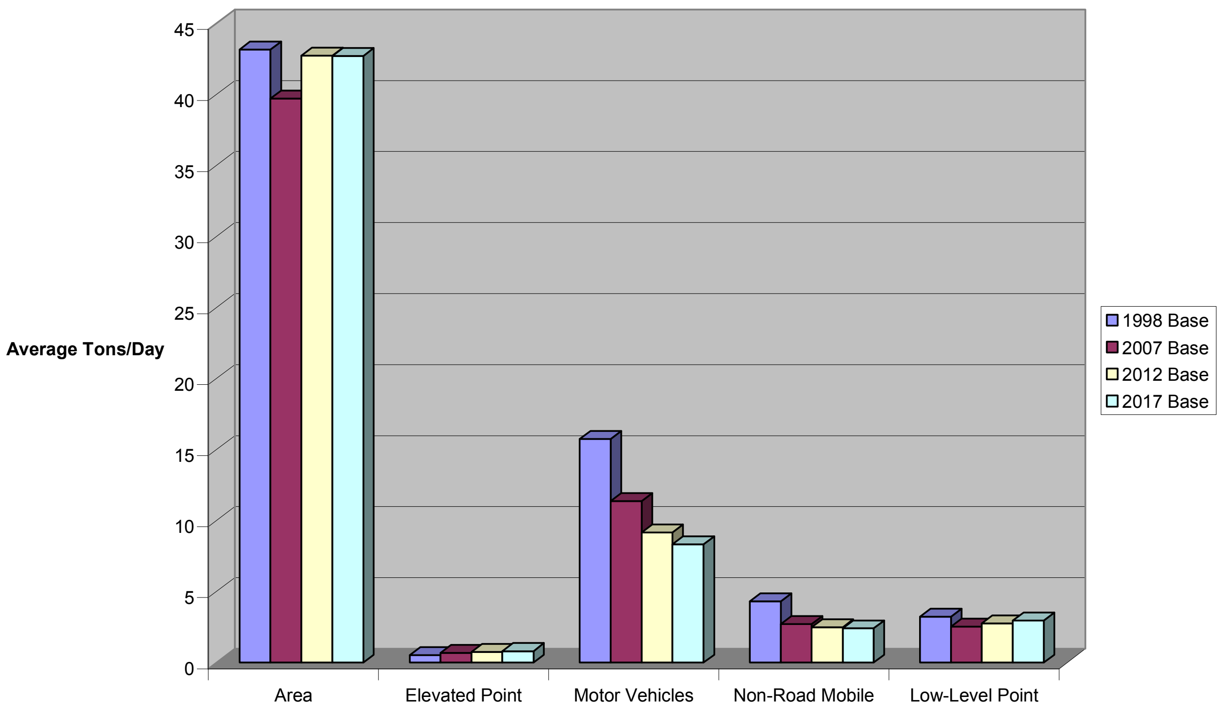

Figure 7-9d. Anderson area VOC episode emissions.

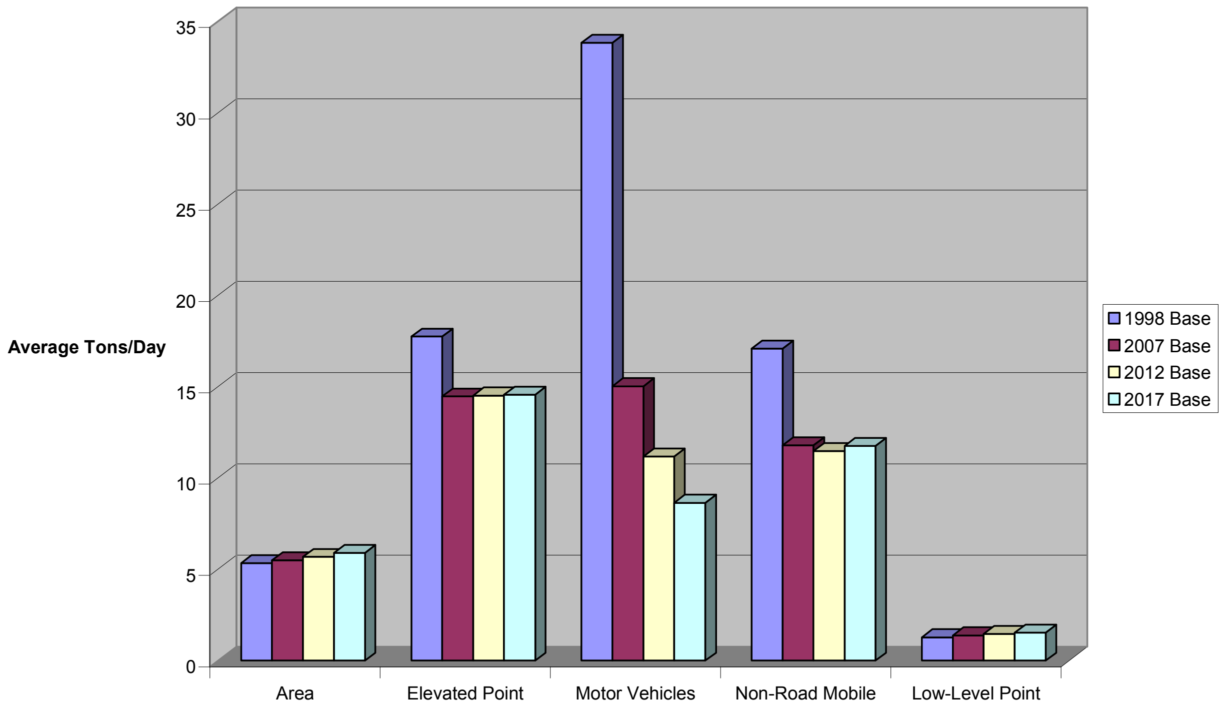

Figure 7-9e. Greenville area NO_x episode emissions.

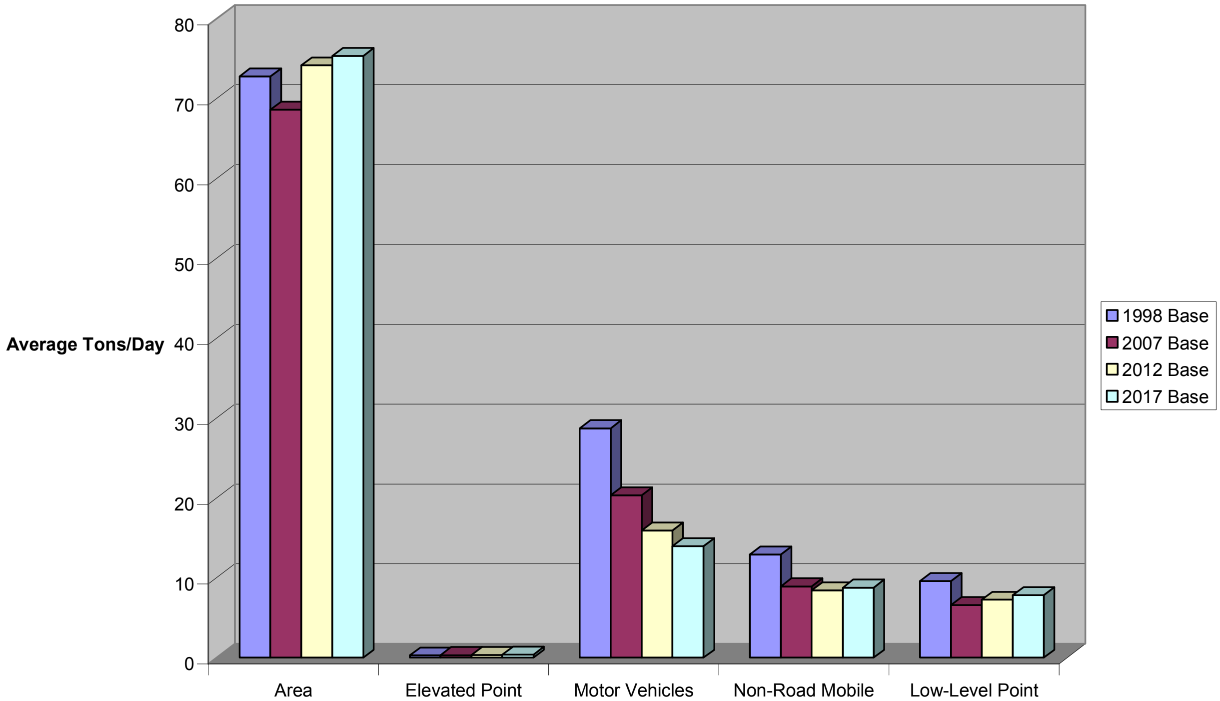

Figure 7-9f. Greenville area VOC episode emissions.

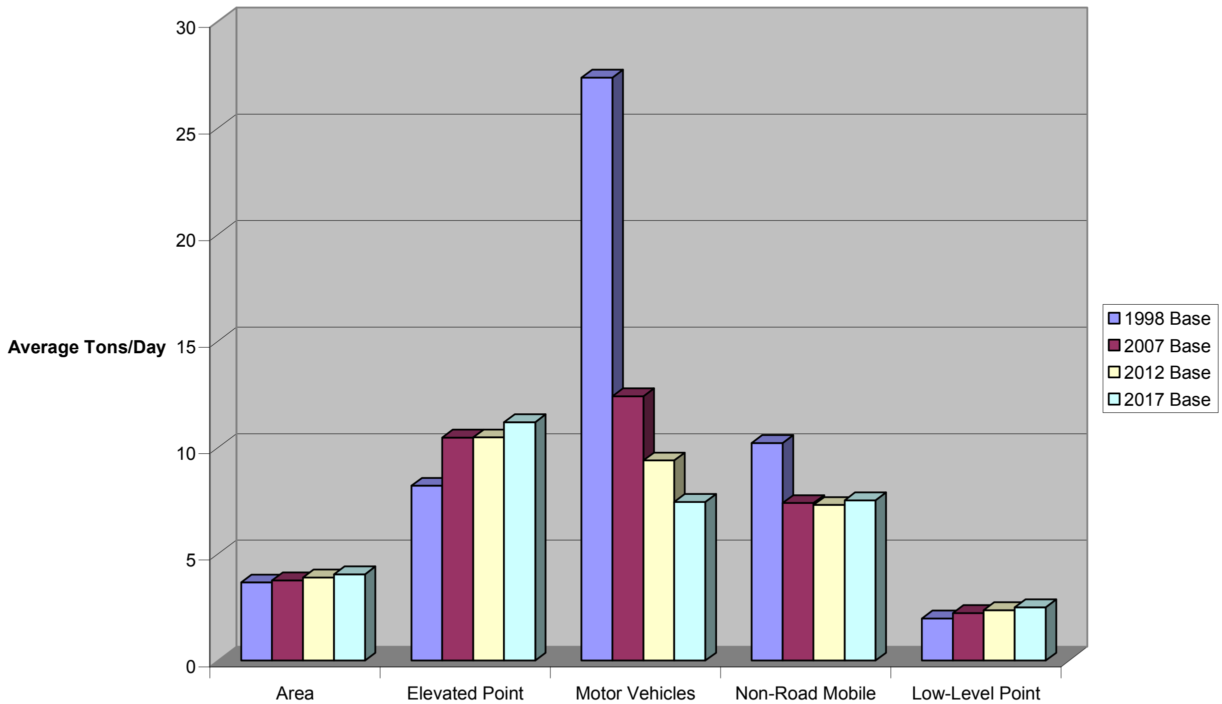

Figure 7-9g. Spartanburg area NO_x episode emissions.

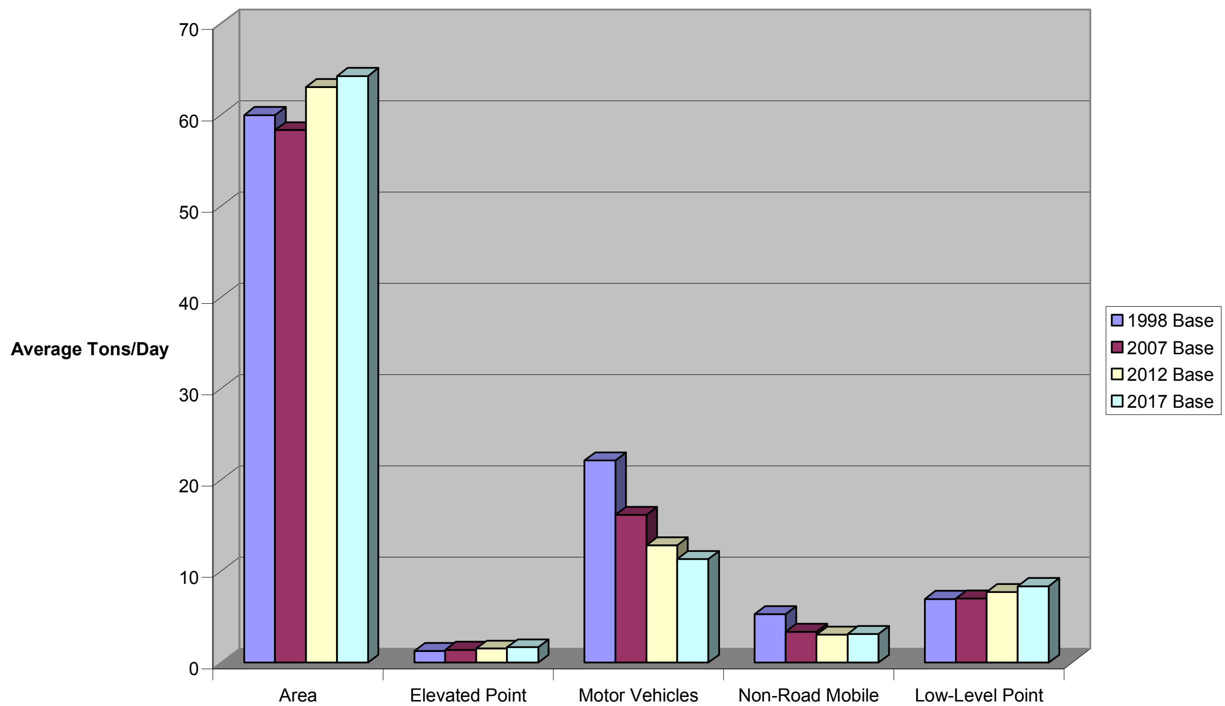

Figure 7-9h. Spartanburg area VOC episode emissions.

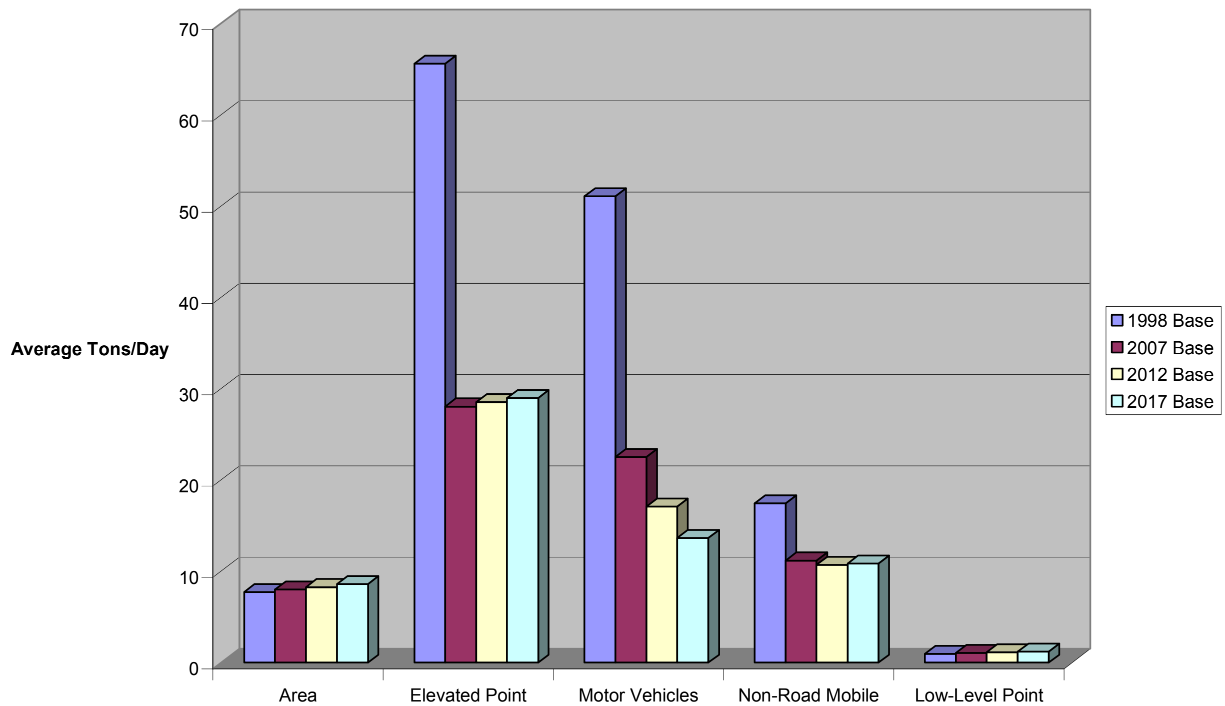

Figure 7-9i. Columbia area NO_x episode emissions.

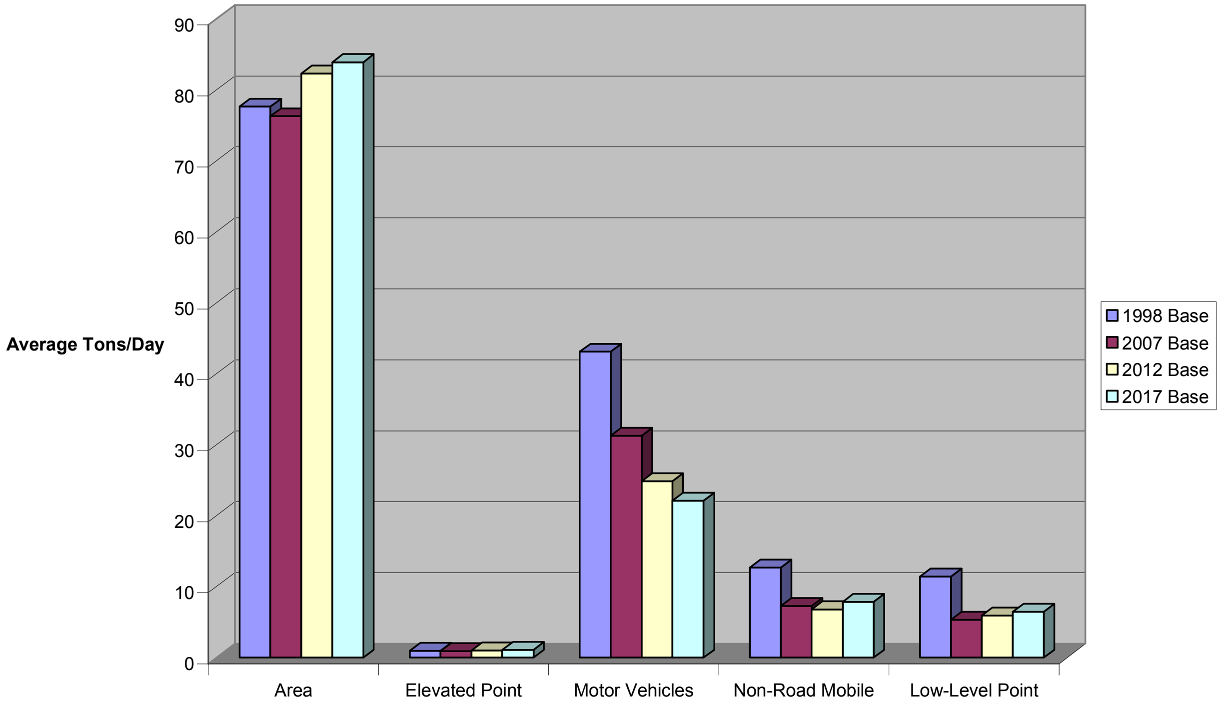

Figure 7-9j. Columbia area VOC episode emissions.

VIII. Application of 8-Hour Ozone Attainment Demonstration Procedures

In this section, we present results from an application of the EPA 8-hour ozone attainment demonstration procedures. These procedures are outlined in the *Draft Guidance on the Use of Models and other Analyses in Attainment Demonstrations for the 8-Hour Ozone NAAQS* (EPA, 1999a). They were adapted for the South Carolina modeling domain and analysis period and applied using the results from the future-year baseline simulations, as presented in the previous section. For ease of reading, all figures follow the text in this section.

A. Overview of the Draft EPA 8-Hour Ozone Attainment Demonstration Procedures

The draft attainment demonstration procedures for 8-hour ozone differ from those for 1-hour ozone in several ways. A key difference is that the modeled attainment test is based on relative, rather than absolute, use of the modeling results. Thus, the test relies on the ability of the photochemical modeling system to simulate the change in ozone due to emissions reductions, but not necessarily its ability to simulate exact values for future-year ozone concentrations. Another difference is that the 8-hour attainment test is site-specific while the 1-hour test focuses on an urban-scale modeling domain. For 8-hour analysis, areas of the domain that are not monitoring sites are only considered as part of a "screening" test. Yet another difference is that modeling comprises a part of the "weight of evidence" for the 8-hour ozone attainment demonstration—a somewhat lesser role, perhaps, than for 1-hour ozone.

The draft EPA guidance on 8-hour ozone modeling recommends that an attainment demonstration include three elements: (1) an attainment test, (2) a screening test, and (3) a weight of evidence determination.

B. Attainment Test

For a monitoring site to pass the attainment test, its future-year estimated design value must not exceed 84 ppb. Future-year estimated design values (EDVs) are calculated for each site, for each simulated day, using "current-year" design values and relative reduction factors (RRFs) derived from future-year and base-year modeling results. The current-year design value for a given site is the three-year average of the annual fourth highest measured 8-hour ozone concentration. The RRF is the ratio of future- to base-year 8-hour maximum ozone concentrations in the vicinity of that monitoring site. The EDV is obtained by multiplying the current-year design value by the RRF.

Attainment Test Application Procedures

For South Carolina, the attainment test procedures outlined in the draft EPA guidance document were adapted for the South Carolina modeling domain and simulation period. Key implementation issues are discussed here.

As described above, relative reduction factors for each site are calculated using simulated ozone concentrations within the "vicinity" of that site. For the 4-km South Carolina subdomain, "vicinity" was defined as within one grid cell of the grid cell in which the monitoring site is located. That is, the nine grid cells surrounding a monitoring site were included in the search for the maximum value. This resulted in a radius of influence of approximately 4 km.

This radius of influence is smaller than that suggested in the EPA guidance document; however, there are good technical reasons to refine the default definitions given by EPA. First, use of a 15 km radius of influence, as recommended by EPA, would mean that the influence zone for a number of sites would encompass, or nearly encompass, other nearby sites. This would occur in the Columbia and Charleston areas for sites that routinely exhibit different concentration characteristics during the simulation period. For example, in the Charleston area, Army Reserve and Bushy Park are located different distances from the coastline and frequently experience very different ozone peaks based on the timing and extent of the sea breeze. The use of a more limited (4 km) radius of influence, in this case, accommodates the geographic and meteorological variability and the observed concentration gradients along the coastline. In the Columbia area, nearby sites Parklane and Sandhill exhibit similar temporal profiles but concentrations that differ by as much as 5 ppb, due to variability in the emissions across the urban, suburban, and industrial portions of the Columbia area. In both cases, a smaller value than the EPA default was used to ensure that the sites were considered independently from one another, and to preserve the site-specific nature of the attainment-demonstration exercise.

We also found as part of the model performance evaluation, that due to concentration gradients in the simulated fields, the maximum value in the nine-cell vicinity of a monitoring site is often much greater than observed. A larger radius of influence would undoubtedly result in even higher values, especially for the coastal sites. Use of these high values is not supported by the observations.

For the South Carolina application, the RRF and EDV values were calculated using the ADVISOR database. The ADVISOR database is designed to allow the user to specify which simulation days to include in the calculation of the RRF. The user may select the day(s) directly or use one of three "automated" day selection options: (1) each simulation day for which the simulated maximum 8-hour ozone value is greater than a user-specified value (including the EPA recommended default of 70 ppb), (2) all observed 8-hour ozone exceedance days, and (3) all days for which the base-case simulation results are within a user-specified range of model performance. The estimated design value (EDV) for each site is then calculated by multiplying the RRF by the site-specific design value. In the ADVISOR database, the user may select the 1996-1998, 1997-1999, 1998-2000, or 1999-2001 design value or the maximum of these.

For the results presented here, we used option (1) above to select the days to include in the analyses, and the 1997-1999 design value. This design-value period best matches (is centered on) the base year of 1998. The 1997-1999 design values are also higher than the 2001-2003 design values that were used to determine 8-hour ozone attainment for areas in South Carolina.

Results from the Attainment Test

Maximum current and estimated design values for the nonattainment sites in South Carolina are given in Table 8-1. This table shows the calculations of the relative reduction factors for 2007, 2012, and 2017. For the Anderson/Greenville/Spartanburg nonattainment area, these sites are the Powdersville monitor located in Anderson County and the North Spartanburg Fire Station monitor located in Spartanburg County. For the Columbia nonattainment area this site is the Sandhill monitor located in Richland County. Table 8-2 contains the maximum current and estimated design values for all of the monitoring sites in South Carolina. These monitors are grouped by the respective areas listed in Section I of this report. The calculation process for the relative reduction factor is the same as used in Table 8-1. The EDVs were calculated using the 2007, 2012, and 2017 future year baselines as the bases for calculation of the RRF. For all sites, the EDV for 2007 is lower than the 1997-1999 DV, and the EDV for 2012 is lower than both the 1997-1999 DV and the EDV for 2007. For 2017, the EDV is lower than the EDV for 2012 for all sites except for Cape Romain. In addition, the values for all sites are less than or equal to 84 ppb. The 2001-2003 design value for these sites is also included in the table; the 2001-2003 design value was the data used to determine South Carolina's 8-hour ozone attainment status. The monitors indicating non-attainment based on 2001-2003 design values are shaded.

Table 8-1a.
Simulated current and future year 8-hour ozone concentrations for the Powdersville (Anderson County) site for the Anderson/Greenville/Spartanburg area.

Simulation Date	Simulated Maximum 8-Hour Ozone (ppb)			
	1998	2007	2012	2017
5/18/98	79	68	69	68
5/19/98	76	68	63	60
5/20/98	82	69	65	63
5/21/98	71	60	59	59
5/22/98	72	65	63	62
5/23/98	70	66	61	58
Average	75	66	63	61
EDV Calculations				
RRF		0.88	0.84	0.81
1997-1999 DV		96	96	96
2001-2003 DV		86	86	86
EDV (1999)		84	81	78

Table 8-1b.
Simulated current and future year 8-hour ozone concentrations for the North Spartanburg Fire Station (Spartanburg County) site for the Anderson/Greenville/Spartanburg area.

Simulation Date	Simulated Maximum 8-Hour Ozone (ppb)			
	1998	2007	2012	2017
5/18/98	78	69	69	69
5/19/98	77	66	64	64
5/20/98	82	70	67	66
5/21/98	76	64	63	62
5/22/98	74	70	68	67
5/23/98	72	67	65	65
Average	76	67	66	65
EDV Calculations				
RRF		0.88	0.87	0.86
1997-1999 DV		93	93	93
2001-2003 DV		87	87	87
EDV (1999)		82	81	80

Table 8-1c.
Simulated current and future year 8-hour ozone concentrations for the Sandhill (Richland County) site for the Columbia area.

Simulation Date	Simulated Maximum 8-Hour Ozone (ppb)			
	1998	2007	2012	2017
5/18/98	60[1]	60[1]	58[1]	58[1]
5/19/98	90	77	74	73
5/20/98	81	69	66	64
5/21/98	78	65	63	62
5/22/98	81	68	66	66
5/23/98	73	72	71	70
Average	80	70	68	67
EDV Calculations				
RRF		0.88	0.85	0.84
1997-1999 DV		91	91	91
2001-2003 DV		88	88	88
EDV (1999)		80	77	76

[1] Since the 5/18/98 maximum ozone concentration is less than 70 ppb, this day's ozone concentrations are not used in the calculation of the RRF.

Table 8-2.
1997-1999, 2001-2003 8-hour ozone design values and 2007, 2012, and 2017 estimated ozone design values for South Carolina ozone monitors.

Area/County	Monitor Name	1997-1999 Design Value (ppb)	2001-2003 Design Value (ppb)	2007 Estimated Design Value (ppb)	2012 Estimated Design Value (ppb)	2017 Estimated Design Value (ppb)
Aiken/Augusta						
Aiken	Jackson	89	81	73	73	69
Barnwell	Barnwell	88	78	71	71	70
Edgefield	Trenton	86	80	72	70	67
Richmond, GA	Augusta	92	83	77	75	75
Anderson/Greenville/Spartanburg Area						
Abbeville	Due West	87	82	78	70	66
Anderson	Powdersville	96	86	84	81	78
Cherokee	Cowpens	91	84	81	78	76
Oconee	Long Creek	87	84	74	72	71
Pickens	Clemson	91	84	81	77	75
Spartanburg	N. Spartanburg Fire Station	93	87	82	81	80
Union	Delta	83	81	74	67	65
Columbia Area						
Richland	Parklane	89	80	79	77	77
Richland	Sandhill	91	88	80	77	76
Richland	Congaree Bluff	72	77	65[1]	63[1]	62[1]
Darlington/Florence Area						
Darlington	Pee Dee	88	82	77	75	73
Rock Hill Area						
Chester	Chester	92	84	83	77	76
York	York	87	84	78	75	72
Coastal Sites						
Berkeley	Bushy Park	79	72	70	67	67
Charleston	Army Reserve	76	71	66	66	65
Charleston	Cape Romain	80	72	71	68	69

Area/County	Monitor Name	1997-1999 Design Value (ppb)	2001-2003 Design Value (ppb)	2007 Estimated Design Value (ppb)	2012 Estimated Design Value (ppb)	2017 Estimated Design Value (ppb)
Colleton	Ashton	83	77	68	66	64
Williamsburg	Indiantown	75	71	62	61	60

[1] Since the Congaree Bluff design value for 2001-2003 is higher than the 1997-1999 design value, the 2001-2003 design value was used in the estimated design value calculation for 2007, 2012, and 2017.

C. Screening Test

The purpose of the screening test is to identify areas within the modeling domain that have high simulated ozone levels but that are not near a monitor. Once identified, these areas are considered in the analyses of future year attainment.

The screening test is intended as an accompaniment to the attainment test and is specifically applied to areas in the domain where the simulated base-case maximum 8-hour ozone concentrations are consistently greater than any in the vicinity of a monitoring site. EPA guidance defines “consistently” to require 50 percent or more of the simulation days, and “greater than” as more than 5 percent higher. Thus, the screening test is designed to be applied to an array of grid cells where the simulated maximum 8-hour ozone concentrations are more than 5 percent higher than any near a monitored location, on 50 percent or more of the simulation days. The screening test procedures are otherwise identical to the attainment test procedures; the current-year design value for the unmonitored area is set equal to the maximum value at any site.

Screening Test Application Procedures

To apply the screening test for the South Carolina modeling domain, all grid cells within the state were considered. For this application, the vicinity of a monitor was defined by the 49 grid cells (or 7 by 7 block of grid cells) surrounding a monitoring site. Since this includes three grid cells in each direction from the grid cell in which the monitor is located, the range of cells is three (3). The distance defined by this 49-cell block is approximately equal to a 15 km radius of influence and is therefore consistent with EPA guidance.

In identifying candidate locations for the application of the screening test, EPA guidance requires that we focus on “areas” where simulated values are consistently higher than any simulated near a monitor, rather than grid cells. “Areas” means not simply individual grid cells, but rather any combination of cells within the same 49-cell block. EPA guidance further defines “consistently” as 50% or more of the simulated days. To allow us to examine the results in this manner, South Carolina reviewed both a list of each 49-cell block for which some cell exceeded the maximum near any site, and the number of days on which this criterion was met.

Results from the Screening Test

No candidate grid cells for application of the test were identified. Thus, the screening test is passed and there is no need to designate additional areas in which to estimate a future design value.

D. Emissions-Based Sensitivity Simulations

The 2007 future-year baseline simulation was used as the basis for emissions-based sensitivity simulations. The sensitivity runs modeled changes in anthropogenic NO_x and VOC emissions to assess the modeling system's sensitivity to changes in emissions. SCDHEC performed eight sensitivity runs consisting of the following:

- 15 percent reduction in NO_x emissions
- 35 percent reduction in NO_x emissions
- 15 percent reduction in VOC emissions
- 35 percent reduction in VOC emissions
- 15 percent reduction in both NO_x and VOC emissions
- 35 percent reduction in both NO_x and VOC emissions
- 35 percent reduction in NO_x emissions, 15 percent reduction in VOC emissions
- 15 percent reduction in NO_x emissions, 35 percent reduction in VOC emissions

The estimated design values for selected runs are shown in Figure 8-1. This figure includes the three monitors that indicate non attainment according to 2001 – 2003 monitor data along with estimated design values for selected sites across South Carolina.

The VOC reduction sensitivity runs indicate the model is relatively insensitive to changes in VOC emissions. Some areas of the state show no change in design value due to VOC reductions while other areas show slight reductions due to reductions in anthropogenic VOC emissions.

The NO_x reduction sensitivity runs indicate the model is sensitive to changes in NO_x emissions. Increasing NO_x reductions produce lower estimated design values. As such, the sensitivity runs indicate South Carolina is NO_x limited for ozone production.

The combined NO_x/VOC emissions reduction runs indicate no additive or synergistic effects due to reductions in both NO_x and VOCs. The estimated design values that occur on the NO_x/VOC emissions reduction runs mirror the estimated design values caused by NO_x reductions. There are isolated cases of ozone disbenefits occurring due to combined NO_x and VOC reductions.

E. Summary of Findings from Application of the Attainment and Screening Tests, and Emissions-Based Sensitivity Simulations

Application of the modeled attainment test indicates that:

- The average estimated design value (EDV) for 2007 is approximately 10 ppb lower than the 1997-1999 observation-based design value. The average EDV for 2012 is approximately 13 ppb lower than the 1997-1999 observation-based design value. The average EDV for 2017 is approximately 16 ppb lower than the 1997-1999 observation-based design value.
- 2007, 2012, and 2017 EDVs for all sites are less than or equal to 84 ppb.

- The attainment test is passed for all sites for the 2007, 2012, and 2017 scenarios.

Application of the screening test indicates that:

- There are no ozone “hot spots” within the state that fall outside of the monitoring network, based on the simulation results for the May 1998 modeling episode period.

The emissions sensitivity runs for NO_x and VOC indicate that:

- South Carolina ozone production is sensitive to changes in NOx emissions. Additional reductions in NOx emissions should have more impact on ozone production than additional reductions in VOC emissions.
- There are no additive or synergistic effects from combined reductions of NO_x and VOC. In isolated cases there are ozone disbenefits from combined reductions of anthropogenic NO_x and VOC.

The attainment test is passed for all sites for the 2007, 2012, and 2017 scenarios.

Use of different base- or current-year design values may alter these findings.

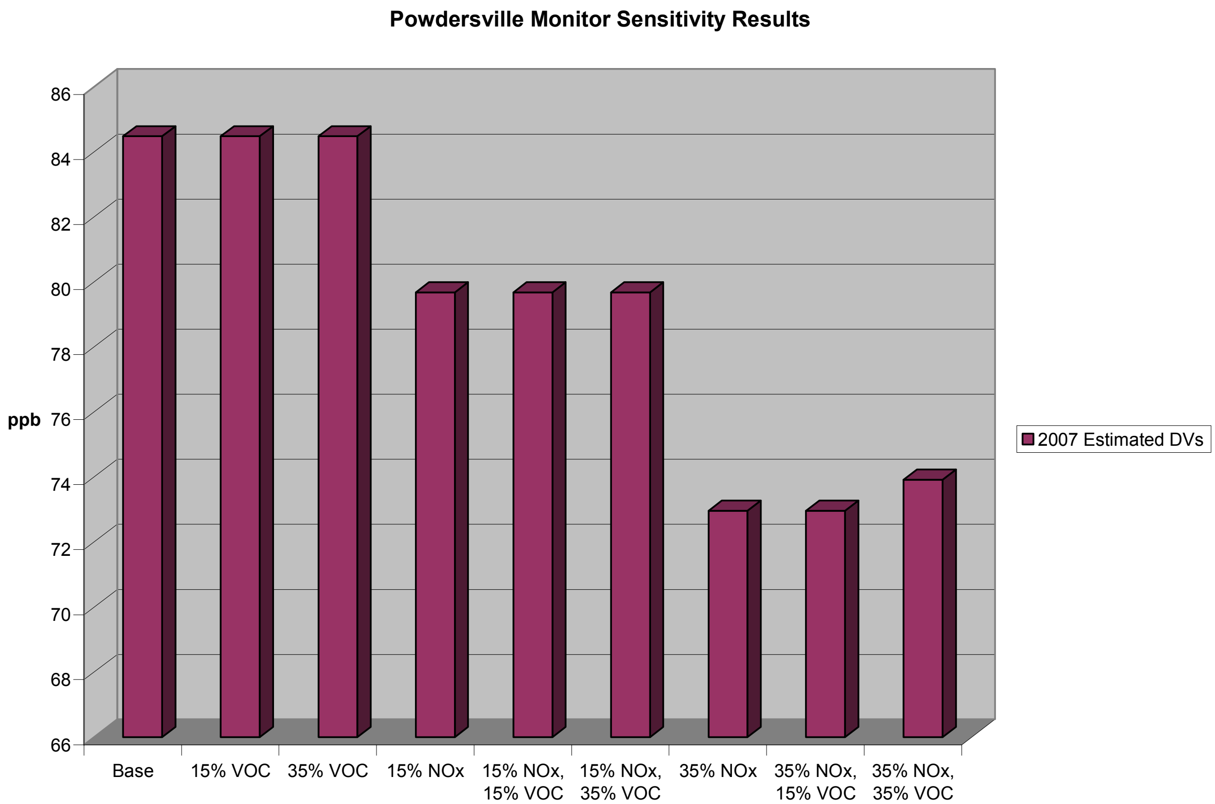

Figure 8-1a. Anderson area sensitivity results.

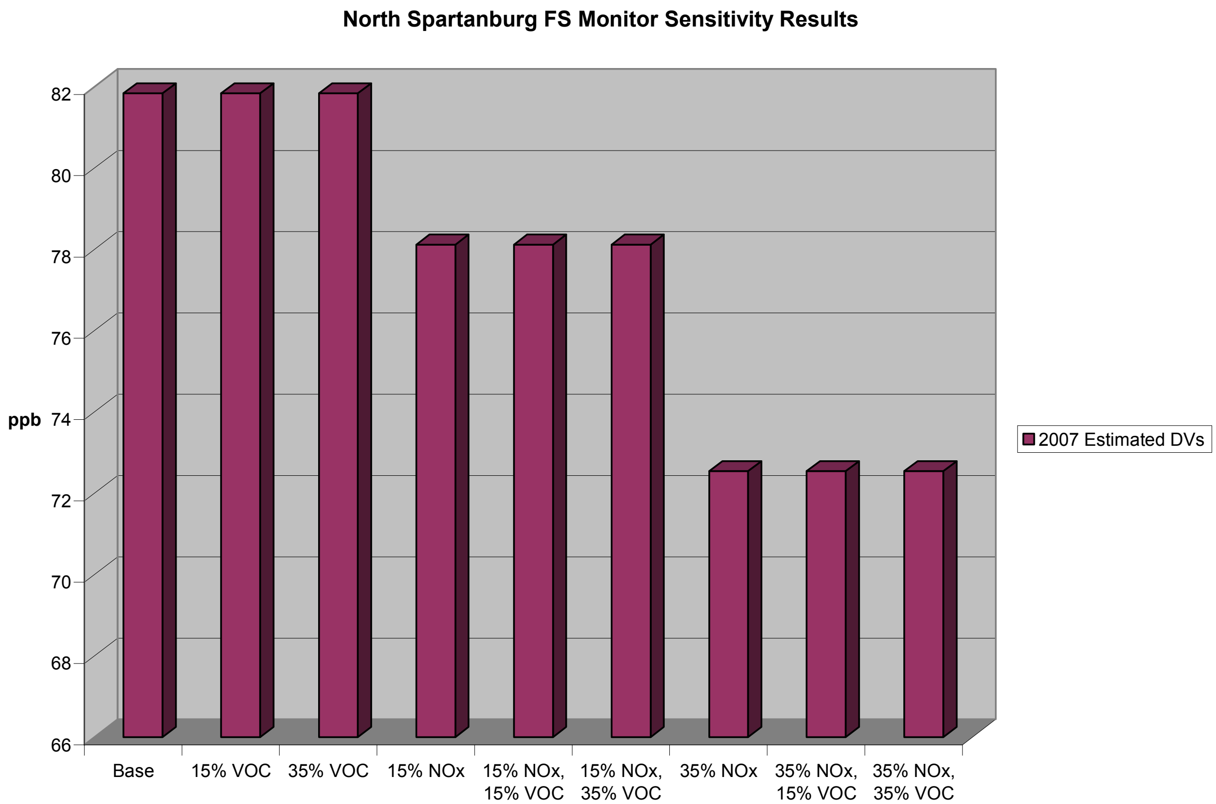

Figure 8-1b. Spartanburg area sensitivity results.

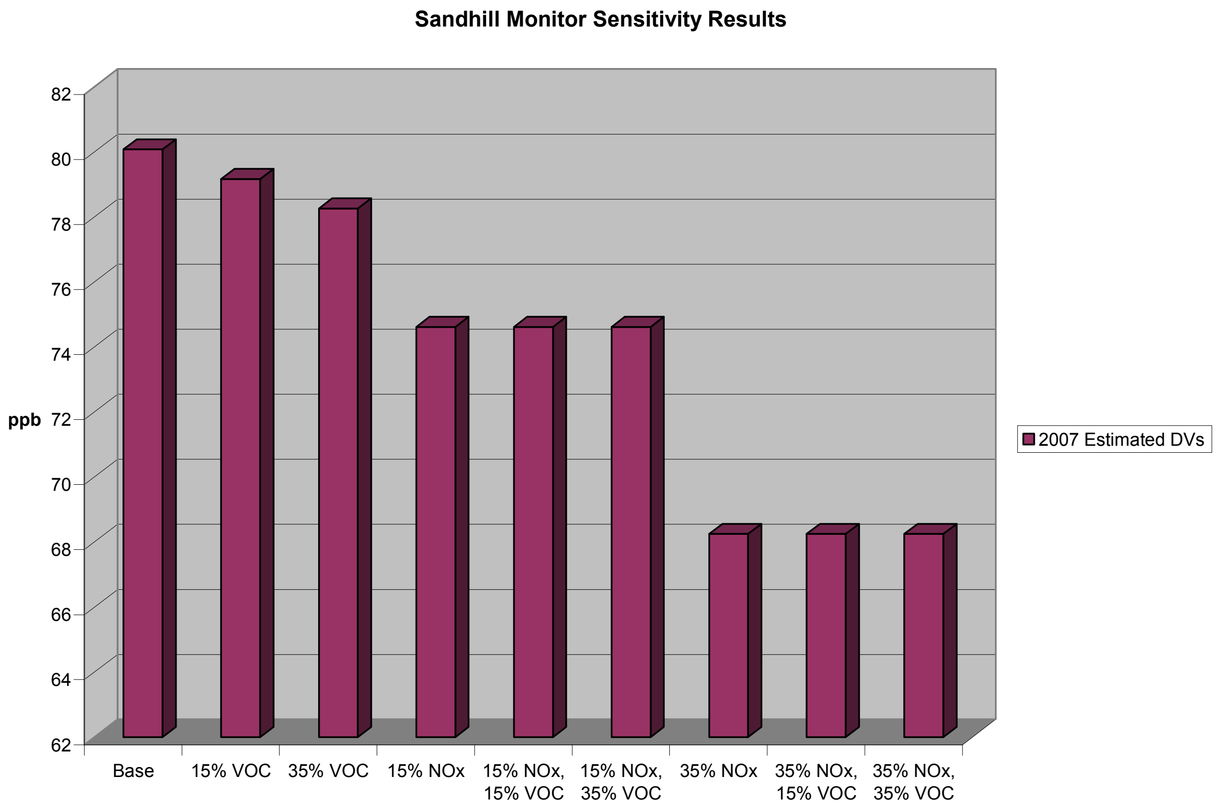

Figure 8-1c. Columbia area sensitivity results.

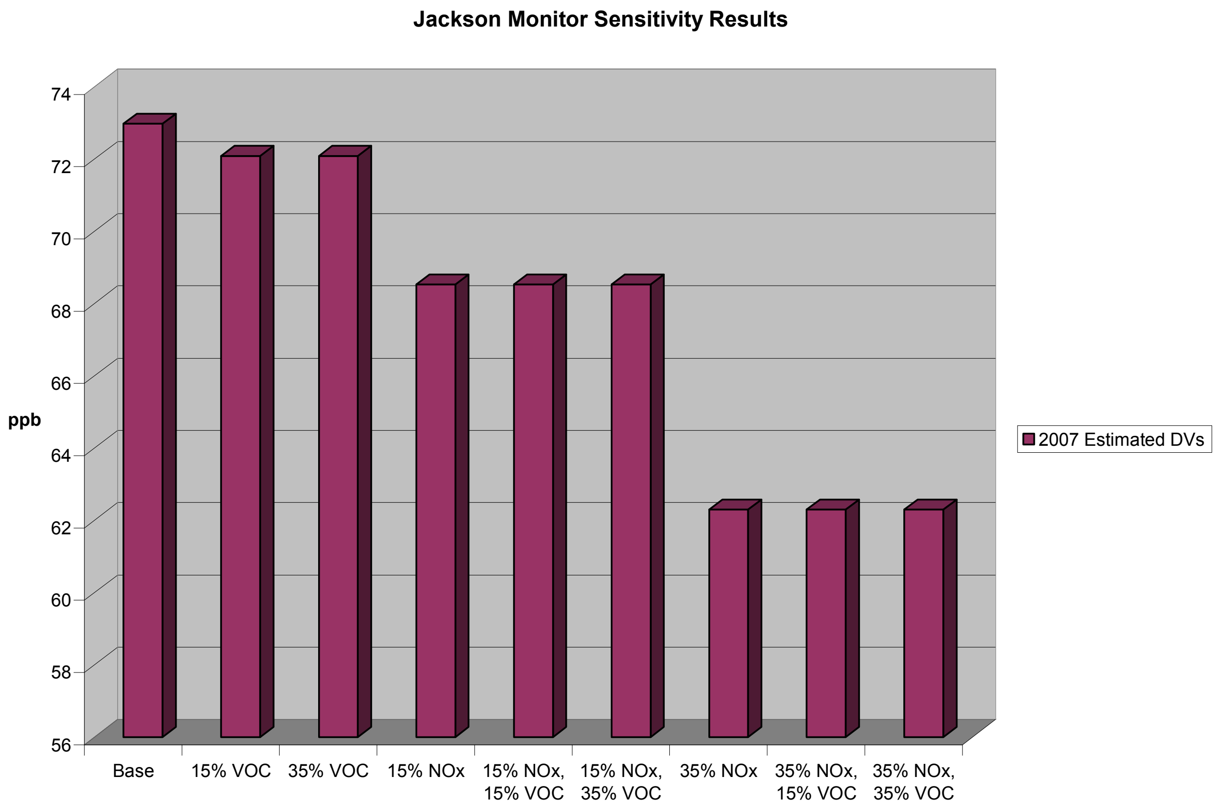

Figure 8-1d. Aiken-Augusta area sensitivity results.

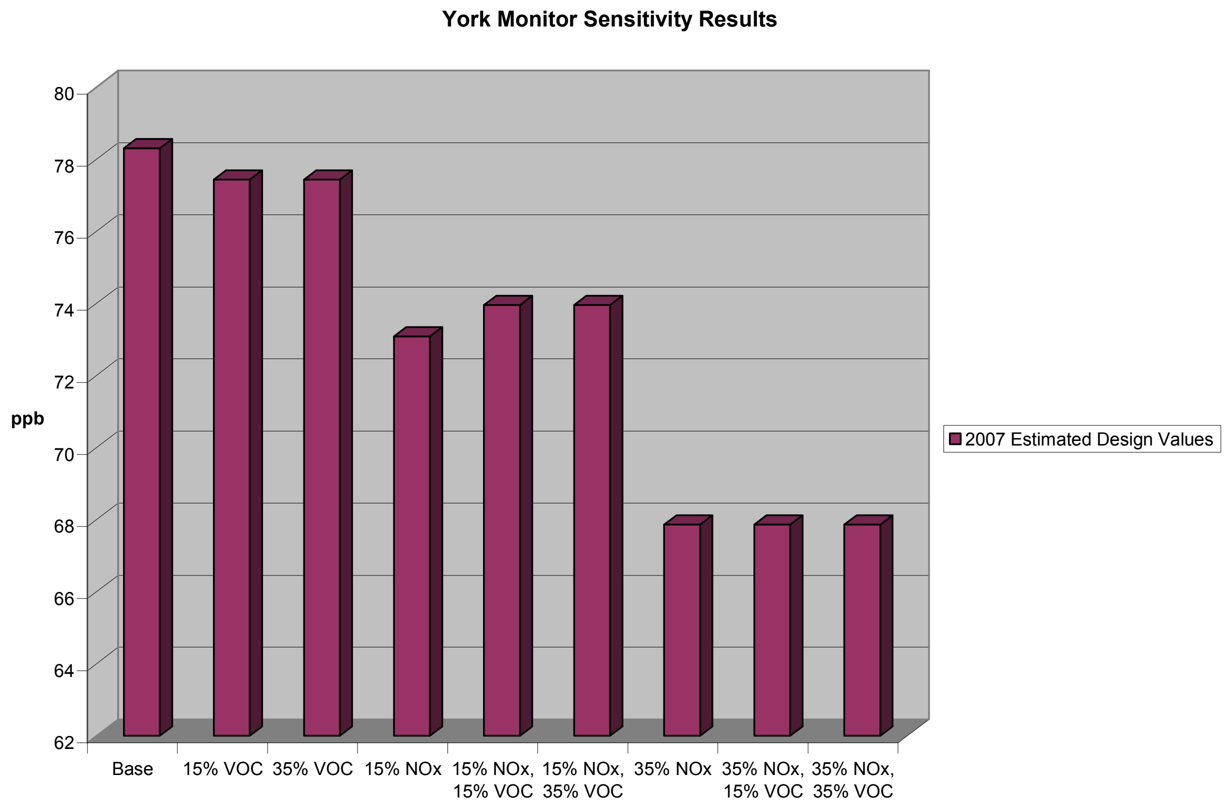

Figure 8-1e. York area sensitivity results.

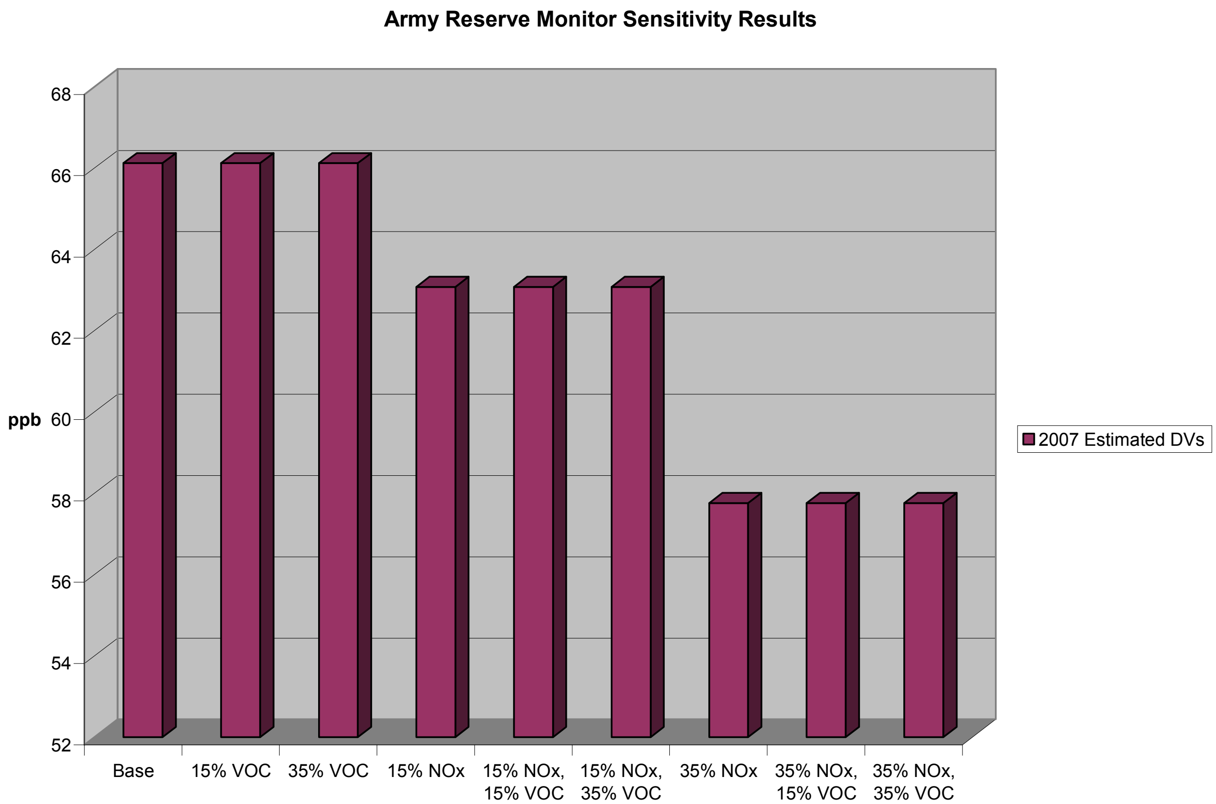

Figure 8-1f. Charleston area sensitivity results.

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IX. South Carolina Modeling Analysis Review Procedures

The review procedures employed as part of the South Carolina 8-hour ozone modeling analysis included quality assurance of the modeling inputs and outputs by SAI and SCDHEC (with emphasis for SCDHEC on the meteorological and emissions inputs) and review and analysis of the simulation results by all study participants.

The quality assurance procedures for the modeling system inputs are described in Sections 3, 4, 5, and 6 of this report. Procedures for quality assurance of the simulation results are described in Sections 6 and 8. The simulation results were presented to representatives from EPA, Region IV and members of the modeling study technical workgroup at meetings held during the course of the study. The results were subsequently posted on the project web site.

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X. Archival/Data Acquisition Procedures

The data, input, and output files for the modeling analysis are available in electronic format. Interested parties should contact Mr. Kevin J. Clark of the South Carolina Department of Health and Environmental Control for information on how to obtain these files. The modeling tools used for this study are all publicly available and can be obtained from EPA (BEIS, MOBILE), NCAR (MM5), or SAI (EPS2.5, UAM-V).

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